Literature Review – DRAFT
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The Physical Environment in Schools: Impacts on Occupants

Children spend a great deal of time inside the educational facilities built for them. Inside these walls children and youth learn math, English, science, and how to socialize with one another. The activities that occur inside our school buildings may be as important as any other to the future of society. Studies have shown significant relationships between physical conditions in schools and impacts on students and teachers, affecting learning and behavior. However, when surveyed about satisfaction with environmental conditions, including lighting, heating, ventilation, indoor air quality, acoustics or noise control and physical security of buildings, forty three percent of the schools responding reported at least one environmental factor as being unsatisfactory (Lewis et al. 2000). A review of the body of literature on physical building attributes of schools and their impacts on occupants is provided in this paper. This is not intended to be a comprehensive review, but rather to provide examples of the methodologies and findings that have resulted from this type of research. Much has been done in the area of comparing open plan classrooms with traditional classrooms, but this literature is not included in this review, nor are studies comparing large and small schools. These physical conditions are considered by the researcher to have less bearing on her current study.

Multiples Physical Environmental Conditions: Impacts on Student Achievement, Attitudes and Behavior

Does the physical environment actually affect the ability of students to learn and teachers to teach? The majority of the studies identified focus on students. It is a challenging issue to separate effects of the physical environment from other factors contributing to student performance and behavior. Clear methodologies for conducting such research are sparse, and the methodologies utilized do not always meet rigorous standards. There appears to be no end to the variety of methodologies and research findings and sometimes the findings in this field contradict one another. Few studies have been replicated, and many studies are based on a small sample.

The extent to which physical features impact the learning process remains unclear, but occupants in school buildings perceive that several types of features affect educational outcomes, primarily physical comfort and health, and classroom adaptability, according to Lackney (1996). He also proposes using an action research approach for learning about the physical environmental features that matter most to building stakeholders, as he did when studying 5 Baltimore City public schools.

In a study of 280 fourth and sixth grade students, those attending a newer school had higher achievement in math, reading, listening and language than those enrolled in an older, “less desirable” facility (Bowers and Burkett 1987). The specific scores used to evaluate achievement were not specified. Similar socioeconomic status was assumed. In addition to improving achievement, Bowers also found that fewer major health problems were reported, fewer disciplinary actions were taken, and attendance was higher in the new school. The researchers recognize that the study is limited because the two schools were not randomly selected, both exist in Upper East Tennessee, and students were not matched for levels of achievement from one school to the other.

In a study involving 47 small, rural high schools in Virginia, student achievement was also shown to be higher in schools with better physical conditions (Cash 1993), using scores of the Test of Academic Proficiency for 11th graders. Physical building conditions were based on the Commonwealth Assessment of Physical Environment. Science scores were associated with schools with better science laboratory facilities. Structural conditions had less of an impact on student achievement than cosmetic conditions. Surprisingly, student disciplinary actions were higher in the schools in better condition. Limitations of the study have been identified by the researcher, including some confusion with specific questions used in the data collection tools and a lack of variance within the school sample.

Only minor effects of the physical environment were shown to affect academic achievement in a study conducted by Chan (1980). The effects of air conditioning, carpet, fluorescent lighting and interior pastel wall color on scores on the Iowa Test of Basic Skills were studied for eighth grade students from 191 public schools in Georgia. Only air conditioning was shown to improve test scores in vocabulary. No differences were observed for the composite, reading, language, work-study and mathematics sections of the test. Fluorescent lights, carpeting or pastel coloring did not significantly affect test scores. A later study by Chan (Chan 1982), found that students (n=119) in a newer school had more positive attitudes about their school than students in the control group housed in an older building (n=96), but this study did not attempt to measure academic performance.

Student attitude towards their school was also measured in a study by Cheng (1994). The impact of the impact of the physical environment on student affective performance, which also includes self-concept, attitudes towards peers, attitudes toward teachers, self-efficacy of learning, feeling of homework overload and intention to drop out of school were evaluated. Higher quality physical environments positively correlated with all measures of student affective performance (including student attitudes about their schools), with the exception of self-concept.

Kindergarten and first-grade children (n=78) were the subjects of a study to determine their preferences for physical environmental features for schools and school yards (Cohen and Trostle 1990) using picture cards of “virtual” environments. Girls had mean scores higher than boys for complexity, color, texture and lighting. Boys preferred larger features. Older children preferred multi-shaped objects, complex items and more dramatic colors, as well as more intense lighting than younger children, who also preferred larger characteristics.

Studies of physical environmental impacts in college classrooms are sparse. Wollin and Montagne (Wollin and Montagne 1981) evaluated the impact of an “amiable” interior environment versus a less pleasing environment, one that was modified by an interior designer. The academic performance of students in 2 introductory Psychology classes in the 2 different college classrooms was compared, as were student evaluations of the teacher, attitudes towards the classroom, and vandalism. Students in the improved classroom performed significantly better on tests and viewed their teacher more favorably. No differences in vandalism were observed.

Student behavior was the focus of a study that compared white walls and cool-white fluorescent lighting, common in school facilities, with blue walls and full-spectrum lighting (Grandgaard 1995). Off-task behavior and mean blood pressure were measured for five 6-year old boys and six 6-year old girls in a public school during 3 phases of the study (before modification, during and after the classroom was returned to its original condition). A decrease of 22% in off-task behaviors were observed in the room with the blue walls and full-spectrum lighting and student mean blood pressure was 9% lower.

Can modifications as simple as rearranging furniture have an impact on student behavior? For one particularly difficult class, Hood-Smith and Leffingwell (1983) observed student behavior before and after the furniture was rearranged. Afterwards, students were more comfortable, felt less threatened, and were more willing to interact with one another after furniture was rearranged. The teacher also felt more in control and actual class work time increased.

Another study by Winett, Battersby, et al. (Winett et al. 1975) examined the impact of rearranging furniture. In this study, individual chair-desks were replaced with small tables and chairs arranged in groups of 4 or 8 in a classroom of 27 sixth-grade students. Individualized instruction and group contingencies were also added, in addition to the architectural changes. The architectural changes alone did not affect significant academic or behavioral changes in students or teachers.

Individual Physical Environment Features

While some studies evaluate the impacts of multiple physical environmental conditions on achievement or behavior, others focus on a single environmental attribute, such as lighting or noise. Associations between reading ability and noise exposure in elementary school children have been shown in multiple studies (Evans and Maxwell 1997). In their study, 116 first and second grade students in two elementary, predominantly Black schools in New York City were evaluated to determine if language acquisition acts as a mediator between noise exposure and reading deficits, and whether short or long-term exposure contributes to reading problems. Chronic noise exposure was correlated with reading deficits, rather than acute exposure. Speech perception, rather than sound perception, acts as a partial mediator.

Christie and Glickman (1980) evaluated 156 students who were asked to perform 60 visually presented tasks from the Standard Progressive Matrices, 1938 version, a type of intelligence test, in either a noisy environment (70 dbA) or a quiet environment (40 dbA). The findings indicate that boys perform complicated problems better in a noisy environment, while girls perform higher in a quiet environment.

A review of the studies that evaluate the effects of lighting on the activity level, achievement, health, visual acuity and fatigue, and health of children was prepared by Fletcher (Fletcher 1983).

Lighting impacts on student behavior was the focus of a study by Ott (1976). The behaviors of first-grade children in 4 windowless classrooms were observed. Standard cool-white fluorescent lighting with solid plastic diffusers provided illumination in 2 of the classrooms, while the others used full-spectrum fluorescent tubes with lead foil to shield the ends of the tubes to reduce X radiation exposure. Children in the room with standard lighting were more fidgety and were observed “leaping from their seats, flailing their arms, and paying little attention to their teachers”, while those with full-spectrum lighting were less nervous and paid more attention to the teacher.

Recently, one particular lighting study has received a great deal of attention. The Heschong Mahone Group (Group 1999) studied the effects of daylighting on student performance. Test scores in math and reading [WHAT Test} were used for 21,000 students from 3 school districts, including Orange Co., CA, Seattle, WA, and Fort Collins, CO to measure achievement. These scores were compared to lighting variables, such as window size, tint, presence and type of skylights, and the amount of anticipated daylight. Students with more daylighting progressed 20% faster on math tests and 26% on reading tests in one year (data for the entire sample on 'progress' were not available). Those with the greater window area progressed 15% faster in math and 23% faster in reading than those with the least, and well designed skylights that diffuse light effectively were also related more rapid progress on test scores. Additionally, students in classrooms in which the windows are operable also progressed more quickly than those with inoperable windows.

Has this research really made a difference? At least 2 studies showed that full-spectrum lighting improved the behavior of students, but are most schools using them today?

Indoor Air Quality: Impacts on Occupants

Studies have shown that physical building characteristics affect occupant behavior. Favorable conditions may result in increased productivity or job satisfaction, reduced absenteeism or turnover rates, and even improve our ability to think and concentrate more effectively. Indoor air quality (IAQ) is one important physical condition that is receiving much attention. Up to 30% of new or rehabilitated buildings in the U.S. may have poor IAQ. Most people spend 80-90% of their time indoors (even more for elderly and children), and the Environmental Protection Agency has consistently considered poor indoor air quality to be among the most serious environmental risks to public (GAO 1999). From 1987 to 1999, federal agencies will have spent almost $1.1 billion (in 1999 dollars) on research related to indoor pollution. Approximately 50% of the funding was spent on lead hazard research, and the other half on indoor air quality (Ibid.). Problems with indoor air quality began to emerge following the energy crisis of the 1970's. Tighter building envelopes, important for energy savings, resulted in reduced air exchange with outdoor air. Complaints from office workers increased during the mid-1970's and 1980's, and research revealed that concentrations of some pollutants were much higher than found in outdoor air. The Government Accounting Office (GAO) (1999) reports that concentrations of pollutants in indoor air can exceed those found in outside air by a factor of 2 to 5. Humidity related health concerns include: infectious diseases from bacteria, viruses and fungi; allergic reactions to dust mites and fungi; nonallergic immunologic reactions, such as hypersensitivity pneumonitis; and myctoxicosis from fungi. Human health impacts may also be caused by pollutants from products and furnishing used inside the building, or contamination from outside air.

One in five school buildings are reported to have IAQ problems (Office 1996). In a study conducted by the National Center for Education Statistics, 18% of schools responding reported unsatisfactory indoor air quality conditions and 26% reported poor ventilation (Lewis et al. 2000). The research regarding impacts of indoor air quality in schools is lacking. Why are schools an important target for research in indoor air quality? The risks of health effects are real. Children are still in the developmental phase and are therefore at a greater risk from indoor pollutants than adults (Bayer et al. 1999). Absenteeism due to asthma, an illness that is exacerbated by indoor pollutants, is approximately 20% in both elementary and high school (Richards 1986, cited in Bayer et. al. 1999). Indoor air pollutants most often measured in schools are formaldehyde, volatile organic compounds, carbon dioxide and aeresolized microorganisms (bioaerosols). There is evidence to suggest that biological contaminants (e.g., allergens and molds) cause symptoms reported in schools for which complaints regarding IAQ were high. Formaldehyde levels generally fall below the threshold level of 0.05 ppm. Little data exists on the impacts of indoor VOCs and aldehydes, but these are suspected of causing adverse health effects on building occupants (Daisey and Angell 1998, cited in Bayer et. al. 1999). The primary building-related problems in schools are inadequate ventilation and water damage that can lead to problems with mold. Deferred maintenance is the primary culprit for these problems (Ibid.). In spite of the challenges of maintaining healthy school environments, Bayer et al. (1999) states, "There have been few good scientific statistically sound studies of school IAQ and its impact on the learning ability of students."

Following is a review of selected studies to demonstrate the variety of methods and findings regarding the impacts of IAQ on building occupants in schools and other types of facilities. This is not a comprehensive review of this body of literature.

Multiple chemical sensitivity (MCS) is one extreme type of illness that has been associated with poor indoor air quality. A small percentage of the population may react adversely to chemicals in the indoor environment occurring at low concentrations. While the medical community is divided, it is a condition related to IAQ that is not being ignored. Brown-DeGagne and McGlone (Brown-DeGagne and McGlone 1999) examined 63 subjects from 3 groups, some with MCS, asthma, and a healthy control group (n=21 from each). The purpose of this study was to learn whether MCS sufferers perform lower on cognitive tasks associated with limbic (frontal and / or temporal lobe) regions of the brain than on tasks associated with non-limbic (posterior cortex) regions. Comparison between groups showed that although MCS sufferers complain more about memory loss, there was no difference memory-change scores. However, the standard deviation for the MCS group is large, possibly due to the differing stages of recovery of the patients. Cognitive test scores for MCS patients did not differ from asthmatics or controls. MCS sufferers and asthmatics performed worse on limbic tasks than those associated with the non-limbic regions, as hypothesized.

Sick Building Syndrome (SBS) is a type of illness with which the building occupant experiences acute health or comfort problems related to building conditions, but the specific illness or cause is unknown. Common symptoms of SBS are fatigue and complaints of respiratory conditions. Possible sources of SB are believed to be one or more of the following:

- Psychological or social stressors associated with the job (e.g., overcrowding, poor management – employee relationships)
- Environmental conditions such as poor lighting or uncomfortable temperatures
- Poor ergonomic conditions

(EPA 1998) A study conducted by Hedge et al. (Hedge et al. 1992) that involved 3155 office workers suggests that SBS is not caused only by exposure to pollutants in the indoor environment, but that personal and occupational factors are also significant in the cause of SBS. A self-report questionnaire that asked questions regarding employee perceptions of ambient conditions, occupational factors, work-related health and SBS symptoms and personal information was used to collect data.

Can individual control over ventilation in workspaces reduce the prevalence of SBS-related symptoms? Menzies et al. (Menzies et al. 1997), conducted a study involving 73 workers (36 on the intervention floor and 37 on the control floor) that demonstrated that installing a system for allowing individual control resulted in decreased occurrence and intensity of SBS type symptoms such as headache; difficulty concentrating; trouble staying awake; skin rash or irritation; irritated eyes; dry or irritated throat; dry of irritated nose; stuffy, congested, or runny nose; cough / difficulty breathing; and musculoskeletal symptoms. Several physical environmental parameters were monitored (e.g., temperature, relative humidity, CO concentrations, fungal spores). An earlier study by Menzies et al. (Menzies et al. 1993) included 1546 full-time workers from 4 buildings to determine whether or not SBS-related symptoms could be reduced by increasing the supply of outdoor air from 20 to 50 cfm / person. Increasing the outdoor air ventilation was not related to decreases in the number of reported symptoms or improved ratings of the interior environment. It is worth noting that the recently revised ASRAE 62-1999 recommends that 15 cfm / person of outdoor air is sufficient for maintaining adequate ventilation.

Another type of intervention study was conducted by Rosen and Richardson (Rosen and Richardson 1999) at 2 daycare centers in Sweden. The impact of free electron production to reduce the number of airborne particles (of a certain size) was implemented to determine its impact on absenteeism. The larger center (n=63) experienced a 55% reduction in absenteeism after the intervention. The smaller center (n=30) also showed a reduction in absenteeism, although it was not significant (perhaps due to the small sample size).

Poor indoor air quality may increase the health risks of occupants, which can impact productivity. A study of 564 telephone customer-service agents at First Card, one of the largest credit card issuer in the US, revealed that as the number of health risks of workers increased, productivity decreased (Burton et al. 1999). Measures of productivity included absenteeism, disability, "amount of time an employee failed to maintain a production standard while at the job".

So, how does exposure to indoor contaminants affect cognitive functioning? Only one such study is included in this review, as few such studies appear to exist. Otto et al. (Otto et al. 1992) exposed 66 healthy young males (ages 18-40) to concentrations of a mixture of VOCs, including 10 of those most commonly found and 10 found in the highest concentrations (excluding known carcinogens) for 2.75 hours. The concentration of each of these chemicals was below the threshold limit value for occupational exposure. No difference in cognitive functioning, as measured on 13 different tests (administered before, during and after exposure), was observed even though subjects complained of mental confusion and fatigue during exposure. This research does not support the World Health Organization report on exposure to indoor pollutants and health effects (cited in Otto et al. 1992) that complex mixtures of VOCs common in new buildings impairs cognitive function and irritates mucous membranes.

The direct impacts from possible exposure to man-made mineral-fiber (MMMF) from ceiling tiles were examined by Rindel et al. (Rindel et al. 1987). Approximately 900 children and 200 adults in 24 kindergartens in Frederiksboro County, Denmark were included in this study. The kindergartens were categorized into one of 3 groups: A) MMMF- products with water-soluble binders in the ceiling; B) MMMF-products with resin-binders in ceilings; or C) No readily visible MMMF-products in the ceiling (control). Data regarding health-related symptoms were collected. Fewer eye and skin symptoms were reported in C kindergartens than groups A or B. There was no difference in symptom prevalence between A and B groups. It does not appear that symptoms are caused by MMMFs derived from the ceiling, according to the indoor air data collected. For adults, however, the airborne MMF concentrations were related to eye symptoms and there was a relationship between skin irritation and the presence of MMMFs on surfaces.

A study by Downing and Bayer (Downing and Bayer 1993) looked not at impacts of IAQ on occupants, but on the impact of technologies on IAQ. A school that had received many complaints from occupants elected to install a Total Energy Recovery System (TERS) in order to increase the outdoor air ventilation while minimizing energy consumption. In this study designed to compare indoor pollutant concentrations in 3 elementary school classrooms under different ventilation conditions, the researchers showed that the ventilation rate of 15 cfm / person, as recommended in ASHRAE 62-1989, is necessary to achieve CO2 concentrations below the guideline of 1,000 ppm. Other pollutant levels, such as formaldehyde and volatile organic compounds were also reduced significantly at the 15 cfm / student ventilation rate.

Fischer (Fischer 1996) conducted a study of students and teachers in 8 schools in which serious IAQ problems had been addressed and resolved by retrofitting existing HVAC systems with TERS. The type of retrofit equipment and associated costs were compared with complaints from students and employees. The results indicate that maintaining proper humidity levels, as can be achieved with TERS, reduces absenteeism and the occurrence of respiratory illness in classrooms, particularly in colder climates. Such systems have been shown to be cost-effective, energy efficient, and readily usable with packaged HVAC systems commonly found in school facilities. In addition the researcher remarked, " Based on existing research, combined with surveys of engineers and school facilities managers conducted as part of this study, the benefit provided to the learning process appears significant".

Green (Green 1974) reviewed 3 studies that examined the relationship between relative humidity and absenteeism. The two studies involving schools showed reduced absenteeism when humidification was supplied during the heating season. Among Army recruits studied, there were fewer incidences of upper respiratory infections in humidified barracks as compared to the non-humidified barracks.

Another study by Reinikainen et al. (Reinikainen et al. 1992) found that workers in a humidified wing of a building showed reductions in symptoms of dryness of the skin and mucosa, the sense of dryness, and allergic reactions when humidification to 30-40% was supplied, as compared to 20-30% under natural, unhumidified conditions. Workers kept a diary of their symptoms, how they perceived their indoor environment and what factors might be contributing to their reported symptoms. Workers perceived a higher level of “stuffiness” under the humidified conditions.

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