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Effect of the physical environment on teacher satisfaction with indoor environmental quality in early learning schools

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EFFECT OF THE PHYSICAL ENVIRONMENT ON TEACHER SATISFACTION

WITH INDOOR ENVIRONMENTAL QUALITY IN EARLY LEARNING SCHOOLS

by

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EFFECT OF THE PHYSICAL ENVIRONMENT ON TEACHER SATISFACTION WITH INDOOR ENVIRONMENTAL QUALITY IN EARLY LEARNING SCHOOLS

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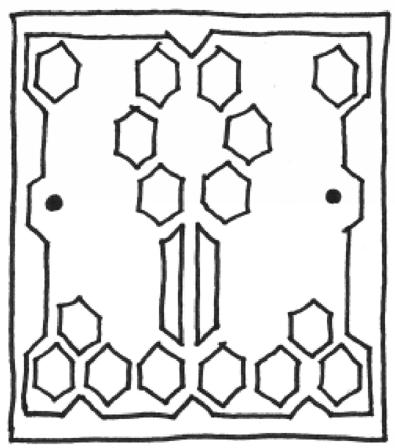
While the quantity and quality of teacher-child interactions plays a key role in emotional and cognitive development for children, there is scant evidence regarding the contribution of physical environment to child outcomes. This study seeks to understand better the relative importance of variables within the physical environment for occupants. The research design targets teachers' satisfaction with the physical environment as the outcome variable, based on the assumption that teachers who are more satisfied with their classroom provide higher-quality interactions with children. Teachers from two early learning schools with a total of 31 classrooms completed a written survey that asked about lighting, acoustics, air quality, job satisfaction and overall satisfaction with the space. The predictor variables are measurements from each sensory domain including illuminance, particulate matter, carbon dioxide and sound pressure level. Results suggest that background noise, lighting and floor area are good predictors of teacher satisfaction. Teachers' perceptions of various sensory domains are related. Organizational satisfaction mediates satisfaction with some features of the physical environment. Discussion includes implications for early learning programs and the design and renovation of classroom spaces.

DEDICATION

To Dana, for the motivation to explore the genius of childhood.



ACKNOWLEDGEMENTS

Educare of Omaha has enabled this study by giving purpose to my inquiry and participating as a full partner in research. The organization's contribution to the health and resilience of the community is my inspiration for taking a closer look at what designers and facility managers can contribute to the loving work of supporting our youngest learners. From teacher's aides to the director of research, to a person, the organization has supported this effort by taking the time to share insights and creating space in their schedule to allow for my data collection. I am grateful to Educare of Omaha for the trailblazing program they deliver and for supporting my study.

RDG Planning & Design has contributed resources and expertise to this project. In addition to designing the schools included in my study, they provided troves of information on the project and facilitated personal connections with Educare of Omaha. By seriously investigating how buildings are actually used, the company has demonstrated a profound commitment to its clients. I am grateful to RDG Planning & Design for sharing with me a vision of community service and excellence in design as an employee and a citizen architect.

I first asked Dr. Lily M. Wang in 2011 if the university could teach me to use research as part of my work as an architect. She said "yes" and has continued to show how much more there was to gain from the halls of the academy. Not only has she guided me through the channels to gain a basic competency in engineering, but she is also a role model to me for how a design professional can succeed in mentoring others while contributing to a community of knowledge. Thank you, Dr. Wang.

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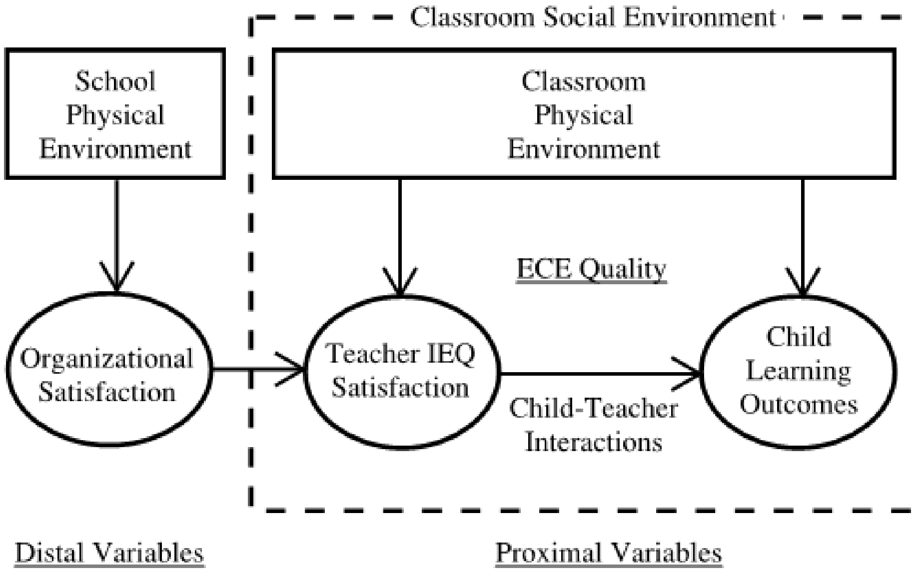
CHAPTER 1 - Introduction

Supporting our youngest learners is a winning strategy for improving the equity, health and resilience of our communities. Especially in developed counties, center-based non-maternal care for infants and toddlers is emerging as an effective support for families, with average enrollment at age 4 for countries in the Organisation for Economic Co-operation and Development (OECD) rising from 79% in 2005 to 84% in 2011 (OECD, 2013). Among 37 countries included in the OECD, the United States is quickly catching up, with enrollment for the same years rising from 65% to 78%. For children age 3 in the United States, the numbers are 35% and 50%. Of 20.4M children under 5 years of age in the United States, 61% were in a regular care arrangement in 2011 and 23.5%, or 4.8M, were in center-based non-maternal care. High-quality early learning schools can be especially impactful for families below the federal poverty line (Burger, 2010) who spend 30% of their income on childcare, compared to 8% for families not in poverty (Laughlin, 2013).

A voluminous literature supports the importance of high-quality programs in helping children prepare for kindergarten. Some examples of this literature include Cryer (1999), Burchinal et al. (2000) and La Paro et al. (2009). However, there is less evidence regarding the contribution of the physical environment to child outcomes in early learning schools. The present study seeks to understand better the relative importance of variables within the physical environment for early childhood education (ECE). The outcome variable for the study is teacher satisfaction with indoor environmental quality (IEQ), based on the assumption that teachers who are more satisfied provide higher quality interactions with children.

While this may be a tenuous assumption, the child-teacher interaction is a fundamental feature of program quality models in the ECE literature (Essa & Burnham, 2001; Dickinson, 2006). In the conceptual framework in *Figure 1-1*, this relationship is represented by the arrow between “Teacher IEQ Satisfaction” and “Child Learning Outcomes.”

***Figure 1-1*: Framework for Program Quality and the Physical Environment**



Evidence supports the role of the physical environment on employee performance and teacher attrition (Carlopio, 1996; Schneider, 2003; Fisk et al., 2011), represented by the arrow between “Classroom Physical Environment” and “Teacher IEQ Satisfaction.” Another hypothesis of the study is that organizational satisfaction in the social work environment mediates teacher satisfaction. With behavioral measures represented in circles and physical measures in boxes, this framework guides the literature review and methodology developed below. The framework posits a direct impact of the physical environment on child learning outcomes. Although this study design does not involve child outcomes, they are included in the literature review as the ultimate aim of early learning programs. The relevance of this quasi-experiment to child outcomes provides consequential validity.

Researchers in building science are also working to refine a model of IEQ in the physical environment. The present study seeks to advance that undertaking with a small but fine-grained analysis of teachers' comfort at two schools. Much of the existing IEQ literature seeks to improve evidence for guidelines pertaining to the operation of buildings to create optimal occupant outcomes or, at least, occupant safety. This study does not provide insight into optimal levels of variables in the physical environment. However, the study does address the relative importance of measurable variables in the physical environment to teacher satisfaction. Findings include a review of the reliability and construct validity of the teacher assessment. More importantly, the study asks which variables in the physical environment are strong indicators of satisfaction and their relative predictive power.

CHAPTER 2 - Literature Review

Following the framework presented in Chapter 1, the literature review investigates how the physical environment affects the health and behavior of employees and students. The review takes an ecological approach to understanding how quality in the physical environment can influence program outcomes for families. Previous findings from building science, ECE and environmental psychology provide context for the present study. Research designs that focus on occupant satisfaction with IEQ are emphasized, with the school conceptualized as both a social work environment for teachers and a social learning environment for students. The sections on IEQ discuss the subjective measures used to assess occupant satisfaction, as well as the various findings related to how measurable variables in the sensory domains combine to a state of satisfaction. The chapter closes with a presentation of IEQ models for occupant satisfaction.

SECTION 2.1 - The Physical Environment in Building Science Literature

The physical environment affects building users in numerous ways, such as job satisfaction (Klitzman & Stellman, 1989; Carlopio, 1996; Kamarulzaman et al., 2011), learning outcomes (Schneider, 2002; Bailey, 2009) and health (Mendell & Heath, 2005; Fisk et al., 2011). Experimental designs typically compare one or more measures from the physical environment to a behavioral outcome. These measurements relate to sensory domains of human physiology including respiratory, luminous, thermal and aural environments. A sample of findings related to air quality, lighting, spatial layout, thermal comfort and acoustics follows. This provides a basis for the following discussion on the combination of features in the physical environment that produce IEQ.

2.1.1- Air quality. The cleanliness and gaseous composition of air is fundamental to human health and performance. This is doubly true for children who experience higher exposure levels of air contaminants than adults. Children 3 to 5 years of age breathe 9.3 liters per minute for their body surface area while adults breathe 5.3 liters per minute. Infants and toddlers are exposed as well to higher concentrations of vapors that are heavier than air (Miller et al., 2002).

Studies of the effect of indoor air quality (IAQ) often use carbon dioxide levels to approximate the amount of fresh air delivered to occupants, called the ventilation rate. Common measures for the cleanliness of air include the concentration of suspended particulate matter and volatile organic compounds. Bioaerosols such as bacteria and fungus are measured typically by culture on artificial growth media or microscopy (Stetzenbach et al., 2004). Determining the precise composition of volatile organic compounds and particulate matter is time consuming and expensive, which may explain why these methods are typically reserved for research and sensitive occupancies.

Achieving air quality is not as simple as providing access to outdoor air since, in many cases, environmental toxins are present outside (Clements-Croome et al., 2008). An especially challenging aspect of air quality is that it is not perceived easily. Occupants may complain about odors, which serve as a good warning for air quality issues. However, occupants are less likely to complain about low ventilation rates or high particulate matter concentrations. This means building users may present behavioral and health symptoms without connecting the issue to air quality (Heinsohn & Cimbala, 2003).

Schneider (2002) reviewed several studies that show higher ventilation rates increase learning. A mechanism he suggests for this effect is that poor air quality reduces occupant health, leading to greater absenteeism and, ultimately, lower student achievement. Mendell and Heath (2005) performed a meta-analysis of thermal and air quality studies that demonstrated how important these dimensions are for student performance. Their study also revealed a lack of strongly designed research to establish the connection between air quality and student performance. Wargocki and Wyon (2007) revealed that higher ventilation rates accounted for variance in some school tasks for students 10 to 12 years of age. Interestingly, students also reported being significantly less hungry when provided more outdoor air. The mechanism suggested for this effect was that better air quality had a moderating impact on stress, of which hunger is presented as a proxy.

Haverinen-Shaughnessy et al. (2011) measured carbon dioxide levels from one classroom in each of 87 schools to determine that test scores increased with higher ventilation rates. This quasi-experiment regressed test scores onto school demographic characteristics and the estimated ventilation rate. As described in Lin et al. (2014), carbon dioxide concentration is a reliable surrogate for bioeffluents from occupants. It is therefore a good measure of the number of occupants in a space and is predictive of occupant odor complaints. However, carbon dioxide concentration does not provide a direct measure of the amount of outdoor air provided to a space (Lin et al., 2014).

Various air distribution strategies and ventilation controls add a layer of complexity to the IAQ literature. Haghighat and Donnini (1999) found that higher perceived air movement was related to greater satisfaction with IAQ in 12 office buildings. Air distribution strategies affect the stratification of contaminants and transmission of contagions. Some newer design solutions, such as displacement ventilation with under-floor air diffusers (Heinsohn & Cimbala, 2003), have not been broadly adopted in schools.

The source of contaminants is a central concern in achieved IAQ. Flooring material is hypothesized to affect IAQ. In assessing asthma risk in schools, Tortolero et al. (2002) performed measured surface loadings of allergens and biological contaminants on carpets in 80 classrooms, finding unacceptable mold and mite allergen levels in about one third of the rooms. Foarde and Berry (2004) compared a school with mostly carpet to one that had mostly tile. The carpet acted as a contaminant sink with higher surface loadings, although aerosol particulate concentrations were higher for the hard flooring. The acoustical and psychological differences between hard flooring and carpet complicate the association of student performance with IAQ. Bullock (2007) showed that students experience higher mathematics test scores in instructional areas with hard floors over carpeted floors. However, this study was limited by a relatively small sample of carpeted classrooms – only 5% of the 111 schools surveyed.

Occupants like to open windows. In comparing schools in a district, Heschong et al. (2002) found that students in classrooms with operable windows progressed 7% faster in reading and math than students in classrooms with fixed windows. Brager and Baker (2009) used occupant surveys from 375 buildings to determine that those with operable windows earned higher scores. Schweiker et al. (2013) found that subjects in a controlled study had elevated skin temperature and drank more water when they were not allowed to open windows in the test chamber. With the possibility of increasing environmental air pollution, mixed-mode buildings that include occupant control of windows may become increasingly important research areas for health.

Building-related illness and sick building syndrome are often a direct result of inadequate air quality (Heinsohn & Cimbala, 2003; Bronsema et al., 2004). Air quality influences occupant satisfaction and performance. By applying previous findings, Wyon (2004) estimated that poor air quality in office environments could reduce employee performance by 6%. When air quality issues are perceived readily, occupants can become very dissatisfied. Schneider (2003) surveyed teachers in Chicago and Washington, DC to find air quality was the top health complaint regarding their facilities, with well over half of the teachers reporting a problem. Just under one third of the teachers reported suffering from a health problem because of poor school conditions.

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) publishes Standard 62.1-2013: *Ventilation for Acceptable Indoor Air Quality* that specifies minimum outdoor air supply rates for buildings based on a dilution approach to controlling contaminants. For a typical classroom, the standard requires approximately 0.43 cubic feet per minute of outdoor air be delivered per square foot (cfm/ft^2). For a typical office environment, the rate would be 0.09 cfm/ft^2. The international standard was developed by the European Committee for Standardization (CEN)/Technical Committee (TC) 156 “Ventilation in Buildings” (1998) and outlined in technical report CR 1752-*Ventilation for Buildings: Design Criteria for the Indoor Environment*. In contrast to ASHRAE standards, CR 1752 provides three categories of attainment based on the estimated percentage of occupants that will be dissatisfied with the air quality. These thresholds of 15%, 20%, and 30% dissatisfied are associated with a ventilation rate ranging from 0.47 – 1.18 cfm/ft^2 for classrooms and 0.14 – 0.33 cfm/ft^2 for open office spaces (Olesen, 2004). The three thresholds in CR 1752 are associated, respectively, with carbon dioxide levels of 460 parts per million (ppm), 660 ppm, and 1190 ppm above the levels measured outdoors.

The International Society of Indoor Air Quality and Climate (Bronsema et al., 2004) developed another design guide, *Performance Criteria of Buildings for Health and Comfort*, and suggest upper limits for specific air contaminants based largely on standards set by the United States Environmental Protection Agency (USEPA) and the World Health Organization (WHO). For inhalable particulate matter (PM_{10}), the maximum 24-hour average concentration is 150 micrograms per cubic meter (μg/m^3), and for respirable particulate matter ($PM_{2.5}$), the limit is 35 μg/m^3 (United States Environmental, 2015). However, the WHO has advised that levels of PM_{10} as low as 10-20 μg/m^3 are associated with increased health risk (Bronsema et al., 2004). The Occupational Safety and Health Administration (OSHA) and the National Institute for Occupational Safety and Health (NIOSH) also set limits for safe exposure to contaminants. NIOSH uses a 10-hour exposure period for establishing concentration limits, while OSHA uses an 8-hour period (Heinsohn & Cimbala, 2003). The OSHA 8-hour average for “particulates not otherwise designated” is 10,000 μg/m^3 of PM_{10} and 5000 μg/m^3 for $PM_{2.5}$ – dramatically higher than air quality suggestions above.

The USEPA’s *IAQ Tools for Schools* action kit (United States Environmental, 2012) is an IAQ guideline written for school administrators and teachers. This resource provides a set of simple Yes/No checklists to identify potential sources of air quality problems. For example, the ventilation checklist contains approximately 75 items, such as

"Checked drain pans for mold and mildew." The resource includes suggestions for addressing items of concern.

2.1.2- Lighting. Human sensitivity to the visible electromagnetic spectrum forms the basis for measures of the luminous environment, such as illuminance (luminous power incident on a surface) and luminance (photometric "brightness"). While visual perception varies by individual, age and luminous environment, lighting designers employ the standardized luminosity function to establish guidelines for IEQ. The spectral distribution of light sources is an important feature of IEQ, with Color Rendering Index and Correlated Color Temperature used together to describe the spectrum and temperature of a source, respectively (Steffy, 2008).

Evidence continues to amass for the effect of illuminance levels, spectral distribution of lamps, and lighting schedules on mood, sleep, safety and performance (Hanford & Figueiro, 2013). Abdou (1997) provides an overview of the importance of quality in the luminous environment as it relates to health and productivity, emphasizing the role of lighting satisfaction in predicting employee morale. Reinhart (2013) summarizes the link between human circadian patterns and light exposure, especially the role of blue light in melatonin suppression. Realizing these benefits of lighting for building occupants is a current focus of engineering practice. Newer ways of characterizing luminous environments, such as daylight glare probability and climate-based daylight metrics, are helping researchers and designers conceptualize high-quality luminous environments (Reinhart, 2013).

Occupant behavior plays an important yet complicated role in quality luminous environments. Nicol et al. (2006) explored how lighting conditions relate to occupant satisfaction, accounting for the roles of daylight and blinds. They found that employees did not significantly adjust lighting levels in response to exterior conditions and employees with access to daylight were slightly more satisfied than those without access to daylight were. Nicol et al. also found that occupants tend to prefer bright environments of about 100 footcandles. In another experiment by Newsham et al. (2003), subjects showed improved mood when provided greater controls of lighting conditions.

The complexity of the lighting environment is highlighted in the glare analysis of Winterbottom and Wilkins (2009). This study considers the luminous effects of window openings and blinds on visual comfort in viewing projected media. The authors propose that illuminance levels were generally too high in the 90 classrooms measured and the combination of glare and fluorescent lighting created highly variable conditions disruptive to learning. Newsham et al. (2009) show that the presence of a window predicts worker satisfaction with lighting, primarily by increasing satisfaction with views to the outdoors. This study also draws strong relationships between lighting satisfaction, overall IEQ satisfaction, job stress and job satisfaction.

Daylight may positively affect student outcomes, although this effect is complicated by the variety of daylight scenarios that actually occur in practice. Aspects of daylight such as glare and solar heat gain may be a negative influence on occupants, while the dynamic lighting spectrum and views may be a positive influence. Heschong et al. (2002) found significant variance between daylight quality and student performance in a large study but, due to methodological challenges, did not have strong findings (Evans, 2006). After reanalyzing the study data to account for preferential teacher assignment to higher quality classrooms, the relationship of daylight to student outcomes remained significant (Schneider, 2002). In a review of the literature, Aries et al. (2015) found "limited statistically well-documented scientific proof" of the benefit of daylight on health. These findings included evidence that daylight reduces depression and better views from windows increase occupant comfort.

In *The Lighting Handbook* (DiLaura et al., 2011), the Illuminating Engineers Society of North America provides recommendations for lighting levels in various space types. Horizontal illuminance at the workplane is a common measure employed for lighting design. Other important metrics that define the quality of a luminous environment include vertical illuminance, the luminance ratio between the "brightest" and "darkest" points in a scene, as well as the daylight metrics mentioned above (Reinhart, 2013). Minimum illuminance levels are generally required for safety, and maximum levels are limited by energy conservation codes. With the prevalence of dimmable, addressable luminaires, designers are less often required to determine a precise design illuminance level, leaving more flexibility to the building users.

2.1.3- Thermal comfort. The physiological balance of thermal energy between the metabolic system and the environment may be the most fundamental dimension of quality in the physical environment. Temperature has an important psychological dimension that forms in the first days of life and continues to impact perceptions and interactions. For example, Bargh and Shalev (2012) found that experiences of physical warmth increased feelings of social warmth in college students. They also showed that longer bathing habits and the use of warmer water are correlated with greater feelings of isolation and loneliness. The authors suggest that humans seek physical warmth in ways similar to their desire for experiences of social warmth.

Occupant thermal comfort depends on air temperature, relative humidity, air velocity and the temperature of surrounding surfaces (mean radiant temperature). Personal factors that affect comfort include clothing, activity level, age and individual difference. Designers and researchers predict occupant satisfaction using models of comfort. The two most common are the heat balance model and the adaptive comfort model. The heat balance model predicts comfort based on the assumption that occupants are universally satisfied at specific combinations of variables. The design process involves weighing the personal and environmental factors in a methodology to predict the percentage of occupants that will be dissatisfied. This estimate is based on empirical findings from occupant surveys using a semantic differential scale of “hot” to “cold” (ASHRAE, 2004).

Models using adaptive comfort have emerged in the last 20 years and predict occupant satisfaction based on outdoor climate conditions. These models generally have a warmer “neutrality” temperature due to adjustments for human seasonal adaptation. Occupants are also more likely to be satisfied with the temperature when they believe they control the ventilation (de Dear et al., 2013). For these reasons, adaptive models are employed commonly in mixed-mode or unconditioned spaces, while the more traditional heat balance model is reserved for buildings with centralized heating, cooling and ventilation. The adaptive model may estimate comfort more effectively than the heat balance model, especially when thermal conditions are uneven, such as occur in naturally-ventilated spaces (Schellen et al., 2012).

Schneider (2002) describes the relationship between student absenteeism and the relative humidity of buildings, suggesting that more students are home sick when humidity levels in the school are high. This may be because mold is more likely to grow at specific humidity and temperature conditions. In a meta-analysis of studies, Seppänen and Fisk (2006) estimated that sick building syndrome symptoms increased by an average of 12% for every 1 degree Celsius increase in temperature. They further found that performance of office workers was optimal at 70.9 degrees Fahrenheit. Temperatures outside a range of 68-73.5 degrees Fahrenheit corresponded to reduced occupant outcomes of around 10%. In another study, higher temperatures caused employee performance on math problems to decline, while also increasing cognitive load as measured by cerebral blood flow (Tanabe et al., 2007).

Describing optimal thermal comfort conditions is not without challenge. The dominant model in the United States is a steady-state heat-balance model defined by ASHRAE Standard 55-2004: *Thermal Comfort Conditions for Human Occupancy*. This standard provides an acceptable operative temperature range based on activity level, clothing level and relative humidity. The temperature may be adjusted based on air velocity, and limits are provided for radiant asymmetry of surrounding surfaces. Standard 55 does contain a section for adaptive comfort models but does not allow buildings with any mechanical cooling to use the expanded temperature ranges offered by this method.

In contrast, the *Performance Criteria of Buildings for Health and Comfort* (Bronsema, 2004) employs a similar methodology to Standard 55 but includes separate recommendations for winter and summer seasons. For an office space, the guide recommends 76.1 degrees Fahrenheit in summer and 71.6 degrees Fahrenheit in the winter. The standard also provides suggestions for designing with the interaction between perceived air quality and thermal comfort. In CEN/TC 156 technical report CR 1752

(1998), the suggested temperature for kindergartens in Europe is 74.3 degrees Fahrenheit in summer and 68.0 degrees Fahrenheit in winter.

2.1.4- Acoustics. The aural environment is related to sound pressure waves by the sensitivity of human hearing. Equal loudness contours are standardized curves that provide a weighting for different frequencies. Although hearing varies by individual and age, the curves allow a signal with sound pressure energy at various frequencies to be converted to a sound pressure level that is related to human hearing (Mehta et al., 1999). Occupant comfort regarding acoustics involves the frequency distribution of sound, the level of background "noise," the transmission of sound between spaces, and the reverberant properties of room enclosures.

Acoustics has a complicated relationship to behavior. Background noise, speech intelligibility and linguistic distractions interact to create aural comfort. The literature relates each of these acoustical properties to occupant behavior, with fewer studies looking at multiple aspects of sound concurrently. One such study performed by Clausen and Wyon (2008) investigated the effect of the physical environment on 99 adults. When given the option of lower background noise levels or the elimination of audible office noise and intelligible conversations, subjects did not have a clear preference. This suggests that individuals differ regarding the relative importance of overall background noise levels and noise distraction, such as conversations. Another example of the complicated relationship between soundscape and satisfaction is provided in Mackrill et al. (2014). The authors found that 24 subjects had significantly different relaxation levels when listening to audio clips with different interventions in a repeated-measures design. Playing a masking sound with the audio clips increased relaxation, and playing nature sound of birds and running water had an even larger effect on relaxation. Interestingly, written information provided to subjects that described the noises they were hearing in the audio clips also increased relaxation. These two experiments suggest that both cognitive and physiological mechanisms may be responsible for individuals' responses to background noise.

Specific characteristics of background noise affect occupant outcomes. Mak and Lui (2012) utilized a 5-point scale on a questionnaire to measure worker satisfaction with IEQ in 38 office buildings. All participants were annoyed similarly by ringing phones and conversations, although those who reported above-average effects on productivity due to the work environment were significantly more annoyed by background noise and closing doors. Office workers under 45 years of age also reported that acoustics was not as disruptive to their productivity as did older employees. Background noises with strong tonal characteristics also influence satisfaction with IEQ. Ryherd & Wang (2008) found that background noise with different tonal characteristics but similar sound pressure levels created various levels of annoyance in adults in office-like environments. However, typical metrics used for acoustical design, such as room criteria and noise criteria, did not predict their subjects' satisfaction. This finding suggests that predominant models of acoustical comfort do not agree well with occupants' self-reported satisfaction.

Considerable evidence shows that sound impacts learning. A study with 90 children 3 to 5 years of age found that equivalent sound pressure level in classrooms predicts pre-reading skills (Maxwell & Evans, 2000). This field quasi-experiment involved the installation of acoustical absorption surfaces in classrooms, suggesting that reverberation time may also have a role in the measured outcome. Shield and Dockrell

(2008) associated occupied equivalent sound pressure levels with student achievement on standardized tests. This study also found that, for schools with outdoor A-weighted equivalent sound pressure levels above 60 decibels (dB) re 20 micropascals (µPa), the maximum sound pressure level predicted students' reading achievement. This finding suggests that loud outdoor noise occurrences interfere with student language outcomes. Ronsse and Wang (2013) compared unoccupied noise levels, reverberation time and binaural room characteristics to student reading and language achievement scores. They found that higher unoccupied noise levels and greater binaural frequency distortion were correlated with higher scores. Their findings suggest that binaural frequency distortion caused by reverberant energy in a learning space may be a better measure of acoustical quality than the more common measure of reverberation time.

A common design standard is ANSI/ASA S12.60-2010/Part 1: *Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools* (American National Standards Institute [ANSI] et al., 2010). For permanent classrooms, this standard recommends a maximum background noise A-weighted equivalent sound pressure level of 35 dB re 20 µPa. Acoustical separations are required to have a Sound Transmission Class (STC) rating of at least 50 between classrooms and 45 between classrooms and hallways. The maximum recommended reverberation time for a typical classroom is 0.60 seconds averaged over the mid frequencies of 500, 1000, and 2000 hertz (Hz).

2.1.5- Spatial arrangement. The amount of room available to occupants affects their behavior, including satisfaction and achievement. Evans (2006) summarized the literature on crowding regarding young children, drawing the strong conclusion that increased occupant density is associated with greater levels of social withdrawal and aggression. Regarding office environments, May et al. (2005) investigated the behavior of 182 receptionists in various medical clinics. Those with less space were less satisfied with the amount of space they had available and were more frequently late to work as well. Lee and Brand (2005) used structural equation modeling with 215 workers from five companies to determine that those with convenient access to meeting spaces reported higher job satisfaction.

The way spaces are organized regarding visual privacy and adjacency are also important features for behavioral outcomes. Maxwell (2007) developed a rating scale to emphasize features of the physical environment that provide rich learning opportunities. The adjacency subscale of the tool includes compatible or complementary areas; support spaces; access to large motor development play; and personal care. For 3- and 4-year olds, the adjacency subscale predicted child competence. A limitation of the study was the small number of subjects (N=79) forming 4 intact classrooms, 2 each in different schools. The study presents compelling evidence for the hypotheses that younger children benefit more from a high-quality physical environment and the physical organization of the classroom is important for child confidence.

Tanner (2008, 2009) developed the Design Appraisal Scale for Elementary schools (DASE), an observational tool based on Christopher Alexander's theory of patterns. Categories included in the tool, such as circulation, meeting places, daylight and views, explained differences in student test scores. While Maxwell's tool considered classroom features, DASE includes the school and surroundings to create a contextual rating of children's experience with the entire school.

There are numerous guidelines for the provisions and arrangement of early learning classrooms. The clearest requirements are those of state regulations relating to the safety and adequacy of childcare environments. These regulations require minimum floor area for each student and access to the outdoors. Regulations may also limit the types of materials and objects that can be in a classroom and provide clear temperature thresholds. Other organizations such as the General Service Administration and the National Association for the Education of Young Children have quality standards that address features of early learning spaces.

SECTION 2.2 - The Physical Environment in ECE Literature

A mature model for quality in ECE has evolved in the literature. Based broadly on Urie Bronfenbrenner's ecological model of child development (1979), the whole child is viewed in the context of a rich social environment that includes the physical environment. Child learning outcomes are linked theoretically to the quality of this social environment. To define quality, researchers organize influences of child outcomes into proximal and distal variables, summarized by Essa and Burnham (2001). Distal variables include community and societal characteristics, such as social support for families and regulations. Proximal variables are characteristics of families and the school, as well as child characteristics, such as gender and temperament.

Child outcomes may be social, behavioral/emotional or cognitive/language. ECE program quality affects these outcomes through two mechanisms: process variables and structural variables. In the ECE literature, process variables are generally considered to have a major effect on outcomes and include teacher interactions, curriculum, the environment and generally those things with which children directly interact (Phillips et al., 2000). Structural variables are traditionally those aspects of program quality that can be regulated and include teacher-to-child ratio, group size, teacher education and teacher wages (Essa & Burnham, 2001).

A common measure of quality in early learning centers is the Early Childhood Education Rating Scale – Revised (ECERS-R). This assessment tool requires a trained observer to characterize several aspects of a classroom environment, typically on one day. Due in part to its early adoption, the measurement has gained prominence amongst researchers and policy-makers. Rated content falls under seven sub-scales: personal care routines, space and furnishings, language reasoning, activities, program structure, interactions, and parents and staff. Ratings in each domain are aggregated generally into a single, global score that hypothetically describes program quality. Numerous findings demonstrate the value of this global measure as a way to improve child outcomes (Burchinal et al., 2000; Atkins-Burnett, 2007). Goelman et al. (2006) also show that ECERS-R scores are predicted by teacher wages, adult to child ratio, teacher education and auspice of school (nonprofit or for-profit).

Gordon et al. (2013) evaluated the validity of ECERS-R to determine that it did not predict child outcomes, although it did relate well to teacher observations of quality. They also suggested the rating scale does not measure six factors and a three-factor model fit outcome data better. However, their three-factor analysis was also not well correlated with student outcomes. One significant relationship that emerged from their study is that the incidence of child respiratory issues is linked to a factor including furnishings, activities and program structure. Gordon et al. recommend ECERS-R be revised to better measure specific dimensions of quality and include scales designed for its intended user, such as child development (researchers), school readiness (educators) or regulatory compliance (practitioners).

Other researchers have questioned the application of ECERS-R in practice, offering suggestions for assessments that represent quality better as it relates to child outcomes (Perlman et al., 2004; Cassidy et al., 2005; La Paro et al., 2012). The prominence of process variables in the conceptualization of quality has also led to the recent popularity of the Classroom Assessment Scoring System (CLASS), another global measure of quality. The desire to pair classroom practice with student outcomes, as well as attention to what is actually happening in the classroom, resulted in the more robust categories of emotional climate and classroom management of CLASS (Atkins-Burnett, 2007). Mashburn et al. (2008) used a multilevel model to evaluate how well different quality rating systems predicted child outcomes. They found CLASS identified more significant relationships with child outcomes than did ECERS-R or an index of nine structural quality items.

While global quality measures such as ECERS-R have a place in early learning policy (Lambert, 2003), more focused tools are gaining the attention of the ECE community. This aligns with a trend in the literature toward a toolkit approach to evaluating program quality. Dickinson (2006) argues that practitioners should employ a heterogeneous set of assessments for different dimensions of quality. In support of this position, the author highlights studies demonstrating that targeted assessments of the classroom environment are better at predicting a specific outcome than global classroom measures. The Early Language and Literacy Classroom Observation (ELLCO) toolkit is one such fine-grained tool. Fundamentally, Dickinson highlights the need for better definitions of quality in early learning environments.

In this context, assessments that target quality in the physical environment may be attractive to ECE professionals. Such tools developed by Maxwell and Tanner are described above. Another such scale to evaluate classrooms, playgrounds and common spaces was developed by Moore (1994), called the Children's Physical Environments Rating Scale (CPERS). This observational assessment features subscales for natural light, acoustic privacy, hiding places, natural ventilation, indoor nature play and gardens. While the instrument's psychometrics demonstrate reliability, there do not appear to be studies linking CPERS to student outcomes. While the pattern of the tool is similar to the ECERS-R, one methodological difference is its inclusion of the entire ECE environment, going beyond the classroom boundaries. Like Tanner's (2009) DASE and Maxwell's (2007) rating scale, the CPERS does not involve physical measurements of environmental conditions.

SECTION 2.3 - The Physical Environment in Environmental Psychology Literature

The literature in environmental psychology adds considerable depth to the understanding of the interrelationship between the physical environment and social formation. Indeed, one of the significant developments in ECE research has been the expansion of the concept of quality to include psychological aspects of the environment, such as emotional climate, teacher-child interactions and child-child interactions (Dickinson, 2006).

These models hold that individuals interact with their environment in dynamic ways, both acting upon the physical environment and adjusting behavior according to sensory feedback (Bronfenbrenner, 1979). As Cobb (2004) demonstrated through observation of child play, humans are the only species to exhibit the tendency to add form and novelty to the environment. The environmental psychology framework places the child in an ecological context where the child does not just develop but, through interactions with nature, "evolves" in biology. Cobb views the biological context of childhood as continuous, not dichotomized by time spent indoors or outdoors. The evolution the child undergoes is the basis for creativity and genius as an adult.

Children's perceptions of the fixity of the physical environment relate to their sense of agency in the world. For example, ECE teachers construct their classroom environments to provision opportunities for learning (La Paro et al., 2009). Other aspects of the physical environment are not modified as easily, such as classroom walls, outdoor play environments, or buildings, streets and neighborhoods. One hypothesis is that the degree of flexibility present in the physical environment and observed manipulation of the physical environment by children are two components of ECE quality. For example, Killeen et al. (2003) found that fourth- and fifth-graders felt a great sense of ownership when they contributed to permanent artwork displays in their schools. The construct of ownership utilized by the study included territoriality, control, personalization and involvement.

Environmental psychologists conceptualize nature as a fundamental relationship that occupants share with the physical environment (Evans, 2006). In a study with 337 children 6 to 12 years of age, Wells and Evans (2003) found that nature provided a buffer to stress, after controlling for socioeconomic status and stressful life events. The authors hypothesized that the mechanism through which nature buffered stress may be social, suggesting that more access to nature created more opportunities for social play. They also posited that access to nature might improve focus. In another study with 500 college students, Benfield et al. (2015) found that those with views to nature had a higher course grade at the end of a semester than those with views to a concrete wall. The students with views to nature also rated the classroom resources higher than did students in similar rooms without views to nature.

Other important contributions from environmental psychology include research on room organization, crowding and color. Maxwell's (2007) study described above found that classrooms with well-defined spaces in the physical environment corresponded with child competence. Considering this finding, quality in the physical environment can be construed as opportunities for challenge and sensory integration. Based on an analysis of several studies, Evans (2006) suggested that density is a better indicator than class size for student outcomes. Several studies have also shown that the color of walls has a significant impact on occupant mood and behavior (Kamarulzaman et al., 2011).

Environmental psychologists often analyze the distal variables that influence occupant outcomes. Evans (2006) suggests that the practice of controlling for social class in studies relating outcomes to the physical environment may confound contributions of the physical environment due to the general collinearity of poverty and environmental quality. A corollary hypothesis is that poor children may exhibit improved outcomes when provided high quality ECE physical environments because they do not otherwise have access to these environments.

SECTION 2.4 – IEQ: Occupant Behavior Measures

IEQ refers to the ability of a building's physical environment to support the health and happiness of its occupants (NIOSH, 2013). This definition is inherently challenging for researchers because the health and happiness of occupants are phenomena that are neither uniform nor static. The section on IEQ models below further investigates this definition of IEQ.

This study is based on the theory that IEQ is a real characteristic of a building's systems and enclosure that can be quantitatively measured and reliably predicted. However, any definition of IEQ is tied inherently to measures of occupant behavior, of which the building science literature employs several. The most common measure is to ask occupants how they perceive IEQ using surveys or interviews. Absenteeism is another measure sometimes used to draw conclusions about the healthfulness and desirability of IEQ to occupants. Occupant performance is used also to assess the impact of IEQ and takes the form of student outcomes in schools and employee productivity in work environments. This section reviews IEQ literature related to surveys and absenteeism. The use of occupant performance measures in building science research is illustrated in the studies reviewed previously in Section 2.1.

Surveys are sometimes used as a proxy measure of actual IEQ because they are generally less expensive to implement than measuring the actual conditions of air quality, lighting, temperature and noise throughout a building. In this diagnostic use, surveys can form part of a system of building maintenance and optimization where occupants help alert building owners to issues that need attention (Hunn et al., 2012). For studies reviewed in the literature, surveys are used principally to create knowledge about how

IEQ influences health and behavior – often in conjunction with measures of the physical environment. The intended use of occupant surveys is fundamental to their development, validity, implementation and consequences for the assessor and occupants (American Educational Research Association et al., 1999).

Many questionnaires of occupant perception of IEQ have been developed and employed in research. Peretti and Schiavon (2011) reviewed the properties of several surveys used in research and practice, as did Dykes and Baird (2013). The Occupant Indoor Environmental Quality (IEQ) Survey™ (Center for the Built Environment, 2004) provided information about how the assessment was developed. Specifically, test developers employed cognitive interviews with seven subjects using a “concurrent think aloud” methodology to investigate item comprehension (Zagreus et al., 2004). This online tool is the most widely adopted building IEQ questionnaire in the United States with over 60,000 survey submissions. The Building Use Studies Occupant Survey (Arup, 2015) is more common in the United Kingdom. Only the Physical Work Environment Satisfaction Questionnaire appears to have been developed with consideration for internal reliability and construct validity (Carlopio, 1996). Surveys that are more recent do not have evidence of construct validity, test-retest reliability, internal reliability or consequential validity (Messick, 1995). This may be due to the low stakes associated with the surveys, which are designed often to protect participants’ identity. Nonetheless, these features of psychometric quality have implications for interpretation of findings.

Occupant IEQ surveys typically have a set of items organized by domains such as lighting, acoustics, thermal comfort, air quality, cleaning and furniture. A semantic differential structure is common for items, with ordinal responses on a 5- or 7-point scale.

Sometimes Likert-type items structured on a symmetric agree-disagree scale are used, as in the Physical Work Environment Satisfaction Questionnaire. For research, surveys are typically anonymous with an online or paper format. Sometimes occupants have the opportunity to provide unstructured responses to a prompt, such as "Are there other issues with the lighting?" Surveys are designed typically to target a specific space that occupants predominantly occupy. One possible confounding variable in assessing perceptions of IEQ is that the building, surrounding landscape and neighborhood of a facility can influence occupants' experiences of the target space for the survey (Dutt, 2012).

An overview of how surveys are employed in the literature is provided in Frontczak and Wargocki (2011). The authors summarized numerous studies that asked office workers about air quality, visual quality, thermal quality and acoustic quality. The review included studies that analyzed the interrelationships of survey responses, as well as studies that linked responses to measurements of the physical environment. A detailed example of a research design implementing occupant responses is provided in Huang et al. (2012). The authors varied the luminous, thermal and acoustic environment in a controlled experiment. Participants reported satisfaction with each domain as well as overall IEQ satisfaction on a 4-point scale with ordinal values of "Quite Satisfied," "Just Satisfied," "Just Dissatisfied," and "Quite Dissatisfied." Findings from this study are discussed in Section 2.6.

There are broader considerations regarding the ultimate utility of self-reported IEQ measures. For example, work environments are not as rooted in place as has been traditionally true. Especially for knowledge workers, the physical and digital parameters of work vary by day, week or month (Davis et al., 2011). In this context, there may be new features that affect perception of IEQ, such as the number and type of regular work locations. Another key consideration regarding IEQ perception is that occupant opinions are relatively unstable in time (Nicol & Roaf, 2005).

Absenteeism is another measure conceptualized as the dependent variable for behavior. Schneider (2002) summarizes findings from several other studies of IEQ and student performance that use absenteeism as an outcome measure. Shendell et al. (2004) investigated yearlong attendance at over 400 classrooms as a surrogate for student health. Specifically, the authors suggest that higher ventilation rates lead to less infectious disease, which is quantified by attendance data. While there is no evidence provided for this reasoning, the significance of findings suggests the metric has good criterion validity.

SECTION 2.6 – IEQ: Models

School facilities are evaluated often by the ratio of the cost of deferred maintenance of a building to the total replacement cost of the building. This metric does not compare well to an educator's perspective of building suitability, primarily because it fails to evaluate the building from the perspective of comfort (Roberts, 2009). Although financial metrics may be the dominant method for addressing IEQ in practice, this review focuses on conditions in the physical environment that relate more directly to IEQ.

Practitioners are working together to conceptualize IEQ across the various domains which have often been independent in practice. One manifestation of this is the increase in design guides and research that treat IEQ holistically. The *Performance Measurement Protocols for Commercial Buildings*, published by ASHRAE et al. in 2010 provides a framework for measuring IEQ in the domains of thermal comfort, acoustics, lighting and air quality (Hunn et al., 2012). In addition to detailing measurements at three levels of increasing sophistication, the standard also compiles suggested limits for many of the variables based on other widely adopted standards. Methods for conducting diagnostic occupant surveys are included in the guideline.

A considerable body of research has illustrated how sensory domains in the physical environment interact to create IEQ. These studies all use some measure of occupant physiology or behavior for validity. Many of the experiment designs combine effects of multiple dimensions of the physical environment and utilize factor analytic techniques to understand correlations. Huang et al. (2012) revealed that of lighting, acoustics and thermal comfort, lighting is the least significant factor. This study used controlled conditions with 120 subjects to establish that both noise (A-weighted equivalent sound pressure level) and operative temperature resulted in occupant discomfort outside of a clearly defined range, while lighting conditions could vary with smaller impact on occupant satisfaction.

Hedge and Gaygen (2010) showed how environmental conditions of temperature, relative humidity, volatile organic solids, carbon dioxide and particulate matter are linked. Temperature has a negative correlation to all measures except carbon dioxide. Lee et al. (2012) found that, compared to temperature, lighting and air quality, sound was the most sensitive factor in college classroom learning environments. Clements-Croome (2013) summarizes several findings to suggest equations relating acceptable temperatures to occupant satisfaction with air quality.

One tendency in the literature has been to identify categories for IEQ based on the tolerance of measurements in each sensory domain. Heinzerling et al. (2013) challenge the notion that higher tolerances in temperature and air quality are related to higher IEQ. Another IEQ research area that spans sensory domains is occupant controllability. Examples of controllability include occupant control of temperature, air velocity, window coverings, acoustics and privacy. Wagner et al. (2007) used surveys to establish perceptions of control over ventilation strategies amongst workers. They found that the perceived effect of interventions to control the indoor climate was a good predictor of comfort. Toftum (2010) concluded that, even when superior IEQ can be achieved with automated controls, occupants are more satisfied when they have the perception of control over the physical environment.

As in the case of ventilation rate measures, controllability can have a confounding effect on a broad range of other measures of the physical environment. Based on surveys, Heschong (2003) reports that teachers expect to be able to control the physical environment of their classrooms. In a study by Lee and Brand (2005), the authors concluded that employees with greater control of the physical environment were more satisfied with IEQ and had higher job satisfaction. Using a design that allowed subjects to adjust temperatures, de Korte et al. (2015) found that satisfaction increased after the temperature and lighting was adjusted by occupants from preset levels.

A position championed by de Dear (2011) is that we are witnessing a paradigm shift in the conception of quality in indoor environments. Instead of targeting steady-state physical conditions that are within prescribed parameters, an adaptive model of comfort is emerging that is organized around occupant control. Using the term “alliesthesia” to refer to that which we find desirable in our environment, de Dear turns to psychological processing to explain the relationships between human physiology and indoor physical environments. In this alternative paradigm, instead of being a product, occupant comfort is a goal to be achieved through the agency of the occupant him/herself (Nicol & Roaf, 2005).

Lehman (2013) suggests an approach to IEQ based on sensory design. This approach emphasizes the nonlinear relationship between features of IEQ and occupant perception, using the "narrative" of the occupant as a way to design spaces. Using neuroscience, Lehman describes the links between distinct sensory experiences for occupants and how they combine to make buildings valuable to occupants. Although Lehman does not explicitly relate the physical environment to perception of IEQ, this approach may help describe and unify the sometimes-contradictory findings of IEQ studies.

The literature has struggled to form consensus for a standard index or metric of IEQ, and some question if this is even possible (Humphreys, 2005; Heinzerling et al., 2013). A central problem is how the psychological state of satisfaction can be correlated to measurable features of the physical environment. Due to the dynamic nature of individual and contextual variables, surveys of the environment measure a moving target (Nicol & Roaf, 2005). Occupant perception of IEQ is also interrelated with the social environment. Carlopio (1996) showed that the physical environment had a moderate correlation with organizational commitment. Newsham et al. (2009) showed that overall indoor environmental satisfaction was linked to organizational satisfaction, a relationship moderated by compensation and management. Veitch et al. (2011) showed that lighting quality could predict employee engagement.

IEQ models provide context for conclusions about the relative importance of the various domains of the physical environment, as well as the relationship of IEQ to other factors. Generally, the physical environment has a much smaller effect on behavior than factors such as individual differences, socioeconomic status or program quality. For example, in Shendell et al. (2004), the authors found a significant correlation between ventilation and school attendance; however, the effect size was an order of magnitude smaller than the role of socioeconomic status and two orders of magnitude smaller than the effect of classroom type – portable or permanent.

Klitzman and Stellman (1989) found that air quality, ergonomic stressors and noise were related more strongly to psychological well-being than other physical conditions like lighting. Schneider (2003) describes how the physical conditions of schools are correlated with teachers' dissatisfaction and intent to change jobs. Using a self-reported survey, Buckley et al. (2004) also found that the quality of conditions at a school is a significant predictor of teacher retention. Clausen and Wyon (2008) performed a controlled study in an innovative design that provided subjects with limited choices for which features of the test environment they could change. Considering views, different types of noise, air temperature and air quality, they found no clear pattern in subjects' selections. They suggest that subject expectations may play an important role in forming IEQ perception and an improved design may first present all subjects with the optimal test conditions before enforcing the reduced IEQ measures.

SECTION 2.7 – Summary

Researchers have studied the effect of the physical environment on students and employees from the traditions of building science, ECE and environmental psychology. The building science literature provides strong evidence of the impact of IEQ on occupant behavior and health. In ECE, the quality of the physical environment is a structural variable that mediates program quality to increase child cognitive and emotional development. The literature in environmental psychology shows the connection between features of the physical environment and social formation.

IEQ is tied inextricably to behavioral assessments of occupant satisfaction; however, it is theoretically a stable feature inherent in buildings. A strong pattern that emerges across research in the physical environment is the central role of occupant control. In the context of building science, strong evidence shows that occupant control of building systems increases IEQ. In the context of ECE, executive function in children increases with quality in the physical environment, suggesting that greater opportunities to interact with the surrounding improve occupant outcomes. The trend towards occupant engagement is clear in models of IEQ that recognize the important role of dynamic environmental conditions for occupant satisfaction, summarized by the concept of alliesthesia.

Behavioral assessments are least mature in the building science literature. With the exception of Carlopio’s tool from almost 20 years ago (1996), building scientists have not constructed occupant surveys that demonstrate the psychometric qualities of assessment tools employed by educators and psychologists. It may be that a focus on the construct validity of occupant surveys may lead to new knowledge about the structure of

IEQ models. In this respect, the traditions of ECE and environmental psychology have much to offer building science. Similarly, small but significant and predictable gains for children can be achieved through increased IEQ as currently understood by building science.

CHAPTER 3 - Methodology

This study hypothesizes that teachers are more satisfied with aspects of their classrooms when there is higher quality in the physical environment. The predictor variables were constructed of physical measurements taken from the classrooms at two early learning schools. In total, there were 23 classrooms in the study. The outcome variables were constructed from a written survey on IEQ completed by teachers from each of the classrooms. There were three teachers in each classroom, and 48 teachers chose to participate in the study.

The study is a quasi-experiment in that it lacks random assignment of teachers to classrooms and schools. Instead, a convenience sample was selected based on study feasibility as well as a consideration of the anticipated significance of findings when weighed against the disruption required to program a field study. Indeed, continuity of care is a key feature of quality in early learning schools, which requires that children remain with the same teachers as they age through the program. The internal validity of this study is marginal due to the lack of random assignment; therefore, any findings are not interpreted as scientific evidence but are suggestive instead for future research.

SECTION 3.1 - Predictor Variable: Physical Environment

Data collection was from November 2014 through March 2015. Both teachers and students were assigned to the same classrooms from August 2014 to May 2015, providing stability in the grouping structure of teachers within classrooms. The primary researcher collected the data. A unique code was assigned to each classroom to maintain teacher anonymity. This code begins with A or B, depending on the school site. For each classroom, occupied data was recorded from 7:30 p.m. until 5:30 p.m. the following day. During a 2-hour window, the researcher relocated the meters, thus the sample is 22 hours for practical reasons. The rooms are utilized generally for early learning programs between the hours of 7:30 a.m. and 5:30 p.m. This 10-hour block of time formed the basis for occupied measures that were averaged over time. In a typical day, children arrive in classrooms from 7:30 to 8:30 a.m. and leave the room for an hour in the morning for gross motor play. Children typically eat lunch in the classroom and nap from approximately 1:00 to 3:00 p.m. Classrooms become unoccupied between 4:30 and 6:00 p.m., by which point all children have left the school.

Access to the building occurred when all of the students were out of classrooms and as teachers were leaving for the day. Occupied measurement in the classroom included particulate matter concentration, background noise levels, illuminance condition, carbon dioxide concentration, air temperature and relative humidity. Two sets of meters allowed for measurements in two classrooms concurrently. Measurements included all 31 classrooms in the two schools, although only the 23 classrooms with teachers who completed the written survey formed the dataset for the study. Exterior environmental measurements were not collected. *Figure 3-1* illustrates the meters' setup, and Table 3-1 describes the equipment employed.

Unoccupied classroom measurements in the study included acoustic reverberation time, illuminance and several observational items. Reverberation time was measured according to the "survey" method in International Organization for Standardization (ISO) 3382-2: *Acoustics – Measurement of Room Acoustic Parameters – Part 2: Reverberation Time in Ordinary Rooms* (2008). While ANSI/ASA S12.60-2010/Part 1 (ANSI et al.,

2010) requires two speaker locations with three microphone locations each, only one speaker location and two microphone locations were used for practical reasons. Room excitation was by integrated impulse response with a series of eight sine sweeps generated by computer software and produced by an omnidirectional speaker. A signal-to-noise ratio that produced reliable results in the 500, 1000, and 2000 Hz bandwidths was established with the software WinMLS (Morset, 2004). A typical setup for room impulse response measurement is shown in *Figure 3-2*.

***Figure 3-1*: Occupied Measurement Meters**

Illuminance was measured at four locations in each classroom relative to luminaires, according to *Standard Measurement and Verification Plan for Lighting Retrofit Projects for Buildings and Building Sites* (Richman, 2012). Taken at night after lamps had reached steady output, the two largest illuminance values were averaged for each classroom. The ratio of the largest to smallest illuminance values created the illuminance ration metric. The lighting power density of each classroom was estimated based on the lamp type and number, and the number of lighting zones controllable with switches was counted. In some cases, lighting zones were shared by two classrooms, in which case the zone was counted as 0.5. The researcher recorded these measurements with the room observation checklist developed for the project. An example of the data collected with this tool is provided in Table A-1 in Appendix A.

Table 3-1: ***Measurement Equipment***

Measurement	Equipment	Protocol
Sound Pressure Level	Larson Davis 824 Sound Level Meter - or - Larson Davis 831 Sound Level Meter	Occupied Measure: 30-second (sec) T-wave Alternans (TWA) Spectral Sound Pressure Level (SPL), Flat Weighting
Particulate Matter	Lighthouse 3016 Handheld Nephelometer, 0.3, 0.5, 1, 3, 5, and 10 micrometer (µm) channels	Occupied Measure: 5-minute Interval, 0.017 cubic foot 10-sec Samples
Temperature (temp), Relative Humidity (RH), Illuminance	Hobo U12-012 Temp/RH/Light Level/External Input	Occupied Measure: 10-sec Interval Point Readings
Carbon Dioxide Concentration	Telaire 7001 CO_2 Sensor	Occupied Measure: 10-sec Interval Point Readings, Logging with Hobo U12-012
Illuminance	Minolta T-10A Illuminance Meter	Unoccupied Measure: USDOE PNNL-21983, Four Locations
Room Impulse Response	Dell Laptop running WinMLS, RME Babyface 22-Channel Audio Interface, Lab.Gruppen LAB 500 Amplifier,and6-Driver Omnidirectional Speaker	Unoccupied Measure: ISO 3382-2, Survey Method with Sine-Sweep Excitation
Observational Measures	N/A	Unoccupied Measure: Study-Specific Classroom Checklist

***Figure 3-2*: Typical Room Impulse Response Measurement Setup**

The observational checklist provided more targeted information than did existing observational measures. It was also faster to implement than tools like Maxwell's (2007) Classroom Rating Scale, Tanner's (2009) Design Appraisal Scale for Elementary Schools, and the USEPA's (2012) *IAQ Tools for Schools* action kit. One compromise of this approach is the loss of fidelity in observational data. In the case of air quality, system-level features of the mechanical system are important. As noted in the *IAQ Tools for Schools* action kit, air intake location, cleaning protocols, air filters and mold control are fundamental for IAQ. These aspects were not included in the present study that focused on features observable from within the classrooms.

The observational checklist collected information that was hypothesized to relate to teacher perception of IEQ, based on the literature review. Color was coded on the presence of warm colors on wall finishes. If one or more wall was a hue of red or orange, in the opinion of the researcher, the room was coded +1. If all walls were neutral in color or were hues of blue, green or purple, the room was coded as -1. The number of live plants in each room was counted and recorded, as was the number of spaces in which children could “hide” from observation. Spaces that provided enclosure but not view privacy, such as a space behind a translucent screen, were also counted. The presence of an exterior door was coded, as was the ability to separate the classroom from adjacent learning spaces. The quality of views to the outdoors was not coded because most classrooms were very similar in views. There were also no examples in the literature of methodologies for quantifying view quality for relatively similar conditions.

Using construction drawings for the two schools, other measures like floor area and fraction of flooring covered by permanent carpet were computed. The position of window blinds was noted ordinally as open, partially open or closed. The orientation of windows in each classroom was coded as +1 for southwest-, south-, and southeast-predominant exposures and -1 for other exposures. The fraction of fenestration that was protected by blinds or other solar shades was recorded. Typically, doors with glazing did not have solar protection and were included in this estimate. The presence of a thermostat that teachers could adjust was coded as +1, and the absence of this was coded as -1. If a thermostat had been tampered with (e.g., covered with a paper towel) or if furniture made the thermostat inaccessible to occupants, it was coded as 0.

For particulate matter suspended in the air, a nephelometer estimated particle counts for five diameter ranges or channels: 0.3-0.5 micrometers (µm), 0.5-1.0 µm, 1.0-3.0 µm, 3.0-5.0 µm, and 5.0-10.0 µm. Samples every5 minutes of 10-second duration provided 253 data points for each classroom over the 10-hour occupied period. Because health guidelines for particulate matter are often provided as mass concentrations (c_{mass}), each number concentration (c_{number}) was converted to c_{mass} using an assumed particle density of ρ = 1.65 g/cm^3 (gram per cubic centimeter), following Tittarelli et al. (2008). The conversion for each channel followed Heinsohn and Cimbala (2003).

Equation 3-1. $$c_{mass} = c_{number} \frac{\rho\pi(D_p)^3}{6}$$

An average mass particle diameter, D_p, was approximated for each channel for use in the above equation by assuming the particles were evenly distributed by diameter across the channel. In fact, particle distribution by diameter is generally lognormal, with more small particles than large ones (Heinsohn & Cimbala, 2003). However, the assumption of a constant frequency distribution for particle diameter simplified calculations and was assumed a good approximation, due to the relatively narrow channel widths. The D_p for each channel was therefore determined by the first moment of a mass distribution, which is proportional to the cube of particle diameter. The lower and upper particle diameters for each channel are represented by *l* and *h*, respectively.

Equation 3-2. $$D_{p(l-h)} = \frac{\int_l^h x(x^3)\,dx}{\int_l^h x^3 dx} = \frac{4\left(x^5\big|_l^h\right)}{5\left(x^4\big|_l^h\right)}$$

The resulting mass average diameters for the five channels are 0.4238 μm, 0.8267 μm, 2.420 μm, 4.238 μm and 8.267 μm. An estimate of respirable particulate matter ($PM_{2.5}$) was obtained by summing the mass of all particles on the first three channels. Inhalable particulate matter (PM_{10}) was estimated by summing the mass of all five channels. The average value of all samples was used for $PM_{2.5}$ and PM_{10}. The greatest time weighted average 15-minute measurement was also generated by averaging three contiguous samples.

Carbon dioxide mole fraction, temperature and relative humidity were measured at 10-second intervals for 7290 samples. A 10-hour average was created for all three variables by averaging the samples. In addition, a maximum time weighted average 15-minute carbon dioxide mole fraction was estimated by averaging 90 contiguous samples.

Sound pressure level was measured in 2,640 30-second intervals across octave bandwidths. These equivalent levels were A-weighted and combined logarithmically to create an equivalent sound pressure level over 10 hours. The 1% and 99% sound pressure levels were also selected from the 30-second sampled data. Reverberation times calculated from computer software based on 20 dB decay were averaged over the mid frequencies to create an average time for a direct sound to decay 60 dB.

The fraction of time lights in the classroom were on during the 10-hour period was estimated using occupied horizontal illuminance measurements taken at 10-second intervals at the ceiling, facing down. For each classroom, a threshold illuminance was estimated by investigation of the data, which was assumed to correlate with the lighting condition. This is possible because lights are turned off predictably during naptime.

A summary of all predictors measured for the study is provided in Table 3-2. All the predictor data is at the classroom level.

Table 3-2: ***Predictor Variables in the Physical Environment***

Variable	Description	Units
	General	
`area`	Usable floor area of classroom	ft^2 (square feet)
`color`	Predominant wall color of classroom	cool or warm
`extdoor`	Presence of a door to the exterior (ext)	yes or no
`carpet`	Portion of permanent flooring that is carpet	ratio
	Acoustic	
`acccontrol`	Ability to separate room from adjacent spaces	yes or no
`rt20`	Reverberation time (rt) based on a decay of 20 dB	seconds
`bnllow`	Typical 4-minute (min) minumum unoccupied A-weighted equivalent sound pressure level (background noise level abbreviated bnl)	dB (decibels) re 20µPa (micropascals)
`bnlhigh`	Typical 4-min maximum unoccupied A-weighted equivalent sound pressure level	dB re 20µPa
`bnldelta`	Difference between `bnllow` and `bnllhigh`	dB
`laeq10`	A-weighted, equivalent sound pressure level (LAeq) during a 10-hour (hr) occupied period	dB re 20µPa
`l1`	A-weighted sound pressure level (l) of 1% threshold during a 10-hr occupied period	dB re 20µPa
`l99`	A-weighted sound pressure level of 99% threshold during a 10-hr occupied period	dB re 20µPa
	Temperature	
`temp10`	Temperature (temp) averaged over 10 hrs from measurements every 10 seconds (secs)	Fahrenheit degrees
`rh10`	Relative humidity (rh) averaged over 10 hrs from measurements every 10 secs	ratio
`tstat`	Condition of a thermostat (tstat) in the room	ordinal
	Lighting	
`switches`	Number of controllable lighting zones in the classroom	numeric
`orient`	Azimuth degree angle of exposure of classroom windows (0º is North)	degrees
`glarecontrol`	Portion of windows with protection from insolation	ratio
`lpd`	Lighting power density (lpd)	Watts/ft^2
`illum`	Average high illuminance (illum)	footcandles
`illumratio`	Ratio between average high and average low illuminance	ratio
`onoff10`	Percentage of time lights are off during a 10-hr period	ratio

Table 3-2: *Predictor Variables in the Physical Environment*, continued

Variable	Description	Units
	Air Quality	
pm2510	Average mass concentration of respirable particulate matter ($pm_{2.5}$) averaged over a 10-hr period	µgrams (micrograms) per m^3(cubic meter)
pm2515	Maximum 15-min time-weighted average mass concentration of respirable particulate matter over a 10-hr period	µgrams/m^3
pm1010	Average mass concentration of inhalable particulate matter (pm_{10}) averaged over a 10-hr period	µgrams/m^3
pm1015	Maximum 15-min time-weighted average mass concentration of inhalable particulate matter over a 10-hr period	µgrams/m^3
co210	Carbon dioxide (CO_2) concentration averaged over a 10-hr period	parts per million (ppm)
co215	Maximum 15-min carbon dioxide concentration over a 10-hour period	ppm

Visual inspection of time-series data plots for each variable provided confirmation of reliability and instrumentation. Appendix A, *Figure A-1* through *Figure A-4* contain plots for two of the 31 rooms measured. Some other notes on data measurements are as follows. Data collection at room A28 for occupied measures terminated at 17:09 instead of 17:30 due to study limitations. For comparison with other data, the measures were extrapolated from the last record from the classroom, which was already unoccupied at 17:09. Data collection for B19 began at 8:00 p.m. instead of 7:30 p.m. on the day prior to occupied measures, although this did not affect the study variables.

At room A27, PM_{10} mass concentration spiked at 5:14 p.m. to 782 µg/m^3. This level is a factor of 10 greater than the typical levels and it was not sustained. Therefore, this data point was thrown out, since it was unlikely the level was caused by regular activities in the classroom because most children had left the center and cleaning begun.

In Room A88, the $PM_{2.5}$ and PM_{10} mass concentrations peaked at 187 µg/m^3 and 2254 µg/m^3, respectively. By investigation, the data suggest these levels of suspension were obtained from normal activity with a steady change in concentration from about 10:20 a.m. to 11:40 a.m. For this room, three days of continuous data was available for particulate matter, and, to understand better activity in the room, all three days were investigated. Plots of these levels in Room A88 are provided in Appendix A, *Figure A-5*, *Figure A-6* and *Figure A-7*. At room B33, measures began at 8:00 p.m. and terminated at 5:00 p.m. The CO_2 meter appears to have turned off due to power supply at 4:45 p.m., and the remaining 15 minutes of measures were extrapolated from the last recording.

Facility age was eliminated as a variable because school was used instead to represent the same test and was less likely to lead to assumptions from non-independence. Similarly, the items for acoustics controllability and thermostat were not used in the analysis because one of the schools had little or no variance on the variable.

SECTION 3.2 - Outcome Variable: Teacher Satisfaction

The self-assessment used was based on the Occupant Indoor Environmental Quality Survey (Center for the Built Environment, 2004). The researcher developed the tool presented in Appendix C because a written survey was necessary for broad participation by teachers and the Occupant Indoor Environmental Quality Survey was only available as a web-based tool. Items related to satisfaction with the social work environment were included based on findings in the literature review. The Quantum Workplace (2015) Best Places to Work survey generated a pool of seven such items.

Modifications to the items from both reference surveys included item wording to increase the item relevance for the target audience. Semantic differential scales were used for IEQ items, and Likert scales were used for organizational satisfaction items (Dykes & Baird, 2013). These scales are ordinal which present limitations to statistical inferences. A 6-point scale was selected for all items. The overall item pool was selected to result in a questionnaire that takes less than 15 minutes to complete. Items were selected to facilitate aggregation into composite scores. Items are aggregated often to improve reliability of assessments (Cohen et al., 2013). Table 3-3 summarizes the survey items.

Participants completed the survey at a staff-training event on March 12, 2015 that occurred at a facility other than the schools involved in the study. All teachers were expected to attend this training, and time was allotted for those who wanted to participate. The target audience was the three teachers in each of the 31 classrooms in the study, for 93 targeted participants. To protect confidentiality, all teachers were provided with a survey that included the consent form in the front matter. Those who did not want to participate could still complete the survey with the knowledge that it would be destroyed if it lacked their signature on the consent form. In total, 87 teachers received surveys, and 70 teachers returned them. Of those returned, 48 teachers consented to participate, and 44 of the consenting teachers were assignable to a classroom included in the study. Teachers were not paid to participate.

Participants are distributed across classrooms and schools based on age, teaching experience, teaching position and length of time assigned to the same classroom. Participant characteristics are described in Table 3-4 and Table 3-5.

Table 3-3: ***Survey Response Items***

	Variable Name	Item
Classroom Size	**sizepersonal**	How satisfied are you with the amount of space available for your use and storage?
	sizechild	How satisfied are you with the amount of space available for children?
	sizeinterfere	Does the classroom size interfere with your ability to do your job?
Classroom Views	**viewcoworker**	How satised are you with the ability to … see your co-workers?
	viewprivacy	How satisfied are you with the privacy of your classroom from the outdoors and hallway?
	viewnature	How satisfied are you with the quality of view to … nature?
	viewinterfere	Do the classroom views interfere with your ability to do your job?
Acoustics	**bnlsat**	How satisfied are you with the sound level in your classroom? (Background noise level abbreviated bnl.)
	stcsat	How satisfied are you with the ability to keep noise from other spaces out…? (Sound Transmission Class abbreviated STC.)
	claritysat	How satisfied are you with the ability for the children to understand you…?
	accprob	Which of the following create noise problems…?
	accinterfere	Do the acoustics interfere with your ability to do your job?
Temperature	**tempcontrol**	Which of the following can you personally control…?
	tempsat	How satisfied are you with the temperature for your comfort…?
	tempchild	How satisfied are you with the temperature for children's comfort…?
	tempprob	Check all that apply about the temperature…: [inverted scale]
	tempinterfere	Does the temperature interfere with your ability to do your job?
Air Quality	**airsat**	How satisfied are you with the air quality in your classroom?
	airprob	Which of the following contribute to odor problems…?
	airinterfere	Does the air quality interfere with your ability to do your job?

Table 3-3: *Survey Response Items*, continued

	Variable Name	Item
Lighting	`lightcontrol`	Which of the following can you personally control…?
	`lightsat`	How satisfied are you with the electric light in your classroom?
	`lightprob`	Check all that apply about the electric light…:
	`naturalsat`	How satisfied are you with the daylight… in your classroom?
	`naturalprob`	Check all that apply about the daylight…:
	`lightinterfere`	Does the lighting interfere with your ability to do your job?
Furniture	`furnadult`	How satisfied are you with the comfort of furniture for adults?
	`furnchild`	How satisfied are you with the comfort of furniture for children?
	`furnadjust`	How satisfied are you with ... the adjustability of furniture?
	`furnlayout`	How satisfied are you with the furniture layout…?
	`finishes`	How satisfied are you with the colors and textures …?
	`furninterfere`	Does the furniture interfere with your ability to do your job?
Cleaning	`cleanorg`	How satisfied are you with the tidiness of your classroom?
	`cleanservice`	How satisfied are you with the cleaning service in your classroom?
	`cleandisplay`	How satisfied are you with the wall display surfaces?
	`cleanprob`	Which of the following are problems…?
	`cleaninterfere`	Does the cleaning and organization interfere with your ability to do your job?
Org. Satisfaction	`enjoy`	I enjoy my work.
	`team`	My team works well together.
	`invests`	My employer invests to make me more successful.
	`paid`	I am paid fairly.
	`purpose`	I understand the purpose of my organization.
	`quit`	It would take a lot to get me to leave this job.
	`friends`	I have a trusting relationship with one or more co-workers.
	`ieqoverall`	All things considered, how satisfied are you with your classroom? (Indoor environmental quality abbreviated ieq.)

Eight items on the survey were answered unanimously across all participants and were therefore removed from the data. All of the participants identified as female. None of the participants reported conditions that affected their hearing; one reported sinuses that affected her smelling; and several reported corrected vision. One participant reported an astigmatism that affected her vision. Three teachers provided write-in comments on a multiple-choice item but did not check the box for the item they listed. One such item was “Which of the following create noise problems? (Check all that apply),” to which the participants responded, “Adjoining bathroom, other classroom uses it and is loud during our nap time” and “Kids on playground outside make noise.” These were coded respectively as “People in other classrooms” and “Outdoor noise.” A second item was “Are there other issues with the lighting?,” to which one participant responded, “Want shades on doors, too bright at nap times.” This was coded as “Sunlight is too bright at times.” The researcher coded these write-in items as if they had selected the more general item listed.

Data preparation included collapsing several items into single variables. Items that listed control features or problem areas were counted, with the number of instances “checked” reported into a single variable. For example, the item “Which of the following can you personally control in your classroom (check all that apply)?” was collapsed into a single item as the number of items checked. In this specific case, “light dimmer” was one of the choices. However, none of the rooms have dimmer switches for the ambient lighting; therefore, the two participants who reported this feature were confused, malingering, or referring to other lighting features in the space. The target construct for the item is the perception of control of the lighting; thus, the “light dimmer” item was retained.

Table 3-4: ***Participant Characteristics by Classroom Type***

		Classroom Type				
		Infant 6 wks-1 yr	Toddler 1-2 yrs	Toddler 2-3 yrs	Preschool 3-5 yrs	Total
Teaching Experience (years)	<1	0	3	1	0	4
	1-3	1	3	3	1	8
	3-10	5	3	2	5	15
	>10	3	7	4	3	17
Age (years)	<30	4	6	5	3	18
	31-40	0	7	4	2	13
	41-50	2	2	1	1	6
	>50	3	1	0	3	7
Time in Classroom	<3 months	2	0	0	0	2
	3-12 months	2	10	3	2	17
	1-3 years	3	4	5	2	14
	> 3 years	2	2	2	5	11
Title	Lead Teacher	2	5	6	5	18
	Associate Teacher	4	7	1	3	15
	Teacher's Aide	3	4	3	1	11
Total		9	16	10	9	44

Table 3-5: ***Participant Characteristics by School***

		School A	School B	Total
Participants		21	23	44
Classrooms	1 Survey	3	4	7
	2 Surveys	6	5	11
	3 Surveys	2	3	5
	Total	11	12	23
Teaching Experience (years)	<1	3	1	4
	1-3	4	4	8
	3-10	10	5	15
	>10	4	13	17
Age (years)	<30	13	5	18
	31-40	3	10	13
	41-50	2	4	6
	>50	3	4	7
Time in Classroom	<3 months	2	0	2
	3-12 months	7	10	17
	1-3 years	6	8	14
	> 3 years	6	5	11
Title	Lead Teacher	9	9	18
	Associate Teacher	7	8	15
	Teacher's Aide	5	6	11

SECTION 3.3 - The Predictive Model

The study hypothesizes that measures of the physical environment can predict teacher satisfaction with IEQ. The proposed model links a specific variable in the physical environment to an outcome measure from the teacher survey. Survey items were grouped into domain composites to improve reliability. As illustrated in the literature review, domains are interrelated; therefore, a secondary hypothesis is that variables from the physical environment in one domain can predict teacher satisfaction in a different domain. Teacher characteristics and organizational satisfaction are hypothesized to mediate these relationships between the physical environment and perception of IEQ. Finally, the physical environment is hypothesized to predict global perception of IEQ. Two IEQ composite scores were evaluated – one that targeted variables most related to human physiology and another that included broader measures, such as furniture and cleanliness.

The hypotheses of this study are at the classroom level as the unit of treatment of the physical environment. However, the theory guiding the research design emphasizes the role of individual differences on behavioral responses to the physical environment. Multilevel modeling with random intercepts at the school and classroom levels provides a concise method for inferential tests of the nested data. However, the limited sample of teachers at both school and classroom levels rendered this approach untenable. For classrooms with more than one participant, one approach would be to average the surveys together, aggregating individual data at the classroom level for analysis. While this could improve reliability, it also makes individual differences such as age, gender, experience and organizational satisfaction less meaningful. Therefore, the study instead selected a representative teacher from each classroom for data analysis. This allowed a multivariate linear regression model comparison approach to data analysis.

Teachers are grouped also by school; therefore, survey responses will likely exhibit nonindependence at the school level. To accommodate this structure, school was included as a categorical predictor in both compact and augmented models. This means each finding must be interpreted with respect to the effect of school. Where school did not explain a moderate level of variance in teacher scores, it was omitted to improve statistical power.

For the results listed in Chapter 4, the following steps were consistent across each domain. Teacher responses to each survey item in a domain were converted to *z* scores. If items counted the number of problems, the score was inverted so that the effect directions were similar. Survey items then were selected to form a composite based on Cronbach's alpha values and inspection of Pearson's correlation tables. Cronbach's alpha is a common measure of item agreement that is used often to support the internal reliability of a set of items. It is similar to an average of item correlation coefficients where the number of items proportionally increases alpha. A high value of alpha, e.g. 0.7 or 0.8, is not necessarily an indication that the items measure a one-dimensional construct. One risk in eliminating items to increase Cronbach's alpha is that the construct validity of the assessment may suffer (Cho & Kim, 2015). Therefore, composites for this study are formed based on judgment with consideration for the resulting alpha.

The newly formed composite score was evaluated for variance explained by school, classroom type, teacher age, teacher experience, teacher organizational satisfaction and the length of time the teacher has been assigned to the classroom. In general, only the variable school explained considerable variance and was retained in the compact model. Finally, each measurement in the physical environment was added to the model to evaluate its predictive power in a 1-degree of freedom test. The software package R was used for all statistical calculations and for preparation of figures (R Core Team, 2012). An example model comparison follows.

Compact Model. *Acoustic composite* = $b_0 + b_1$ (*school*) + error

Augmented Model. *Acoustic composite* = $b_0 + b_1$ (*school*)
+ b_2 (*reverberation time*) + error

To test the final hypothesis, the composite scores are aggregated to form a global IEQ score that was similarly regressed onto variables in the physical environment. A summary of the variables in this project and the hypothesized domains is listed in Table 3-6. Table B-2 in Appendix B follows a similar format.

Table 3-6: ***Study Hypotheses***

Domain	Response Variable	Predictor Variable	Mediator
Size	**sizepersonal, sizechild, sizeinterfere**	**area**	**school, crtype orgsat, tenure, teachage**
Views	**viewcoworker, viewprivacy, viewnature, viewinterfere**	**area, color, blindsopen, glarecontrol**	**school, crtype orgsat, tenure, teachage**
Acoustics	**accoverall, bnlsat, stcsat, claritysat, accprob**	**acccontrol, rt20, bnllow, bnlhigh, laeq10, l1, l99**	**school, crtype orgsat, tenure, teachage**
Lighting	**lightoverall, lightcontrol, lightsat, lightprob, naturalsat, naturalprob**	**illum, illumratio, lpd, glarecontrol blindsopen, onoff10, orient**	**school, crtype orgsat, tenure, teachage**
Temperature	**thermcontrol, thermsat, thermprob, thermoverall**	**tstat, temp10, rh10**	**school, crtype orgsat, tenure, teachage**
Air Quality	**airsat, airprob, airoverall**	**pm2510, pm1515, pm1010, pm1015, co210, co215**	**school, crtype orgsat, tenure, teachage**
Furnishings	**furnadult, furnchild, furnadjust, furnlayout, finishes, furninterefere**	**area, color, carpet, plants, hiding**	**school, crtype orgsat, tenure, teachage**
Cleaning	**cleanorg, cleanservice, cleandisplay,cleanprob, cleaninterfere**	**carpet, plants**	**school, crtype orgsat, tenure, teachage**
Overall IEQ	**ieqoverall**	all measures in the physical environment	**school, crtype orgsat, tenure, teachage**

CHAPTER 4 - Results

SECTION 4.1 - Survey Findings

The preliminary dataset for analysis was formed from responses on 45 survey items by 44 participants. Teachers in the same room answered similarly on the 38 survey items related to IEQ, although inter-rater reliability was low. In rooms with 2 or 3 teachers, the intraclass correlation coefficient (two-way, consistency type) ranged from 0.31 to 0.83, with an average of 0.56. *Figure 4-1* shows how two teachers in the same classroom responded on items using the scale of 1 (dissatisfied) to 6 (satisfied). Classroom A18 demonstrated good agreement, with an intraclass correlation of 0.83, while classroom B97 had a poor intraclass correlation of 0.31.

***Figure 4-1*: Classrooms A18 & B97 Teacher Agreement**

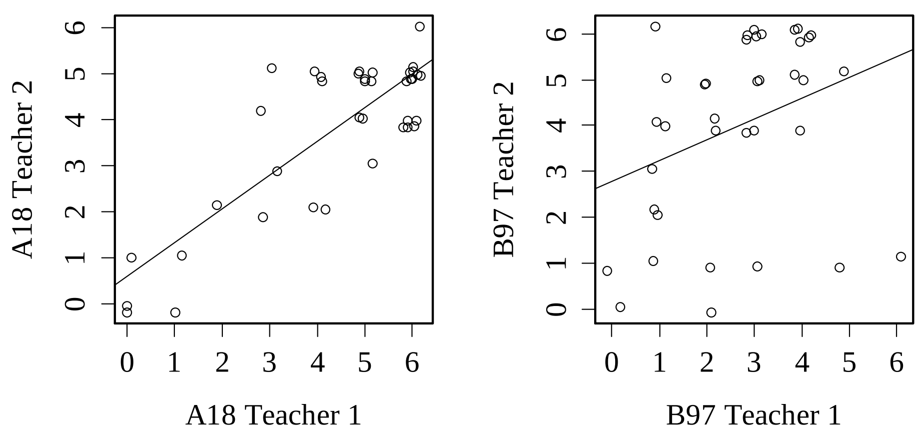


Figure 4-2 illustrates the agreement between scores in classrooms with three teachers. Classroom A19 demonstrated good agreement with an intraclass correlation of 0.77, while classroom B12 demonstrated poor agreement with an intraclass correlation of 0.41. The histogram of responses from two teachers in Room B89 presented in *Figure 4-3* illustrates the low reliability of raters.

Figure 4-2: **Classrooms A19 & B12 Teacher Agreement**

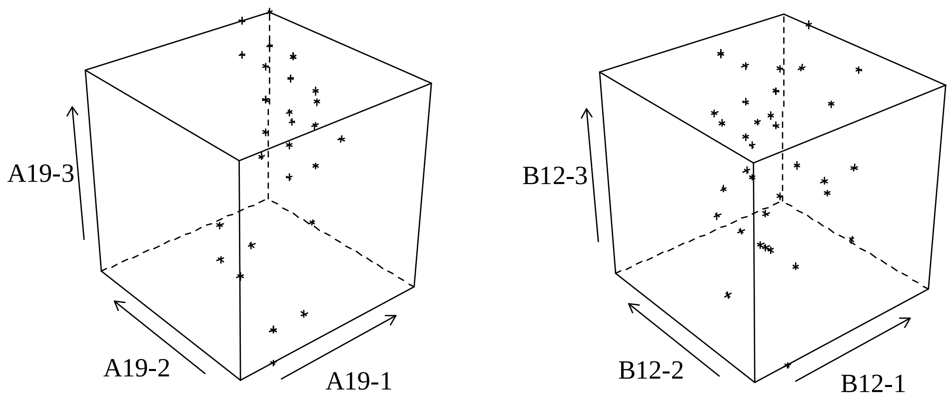
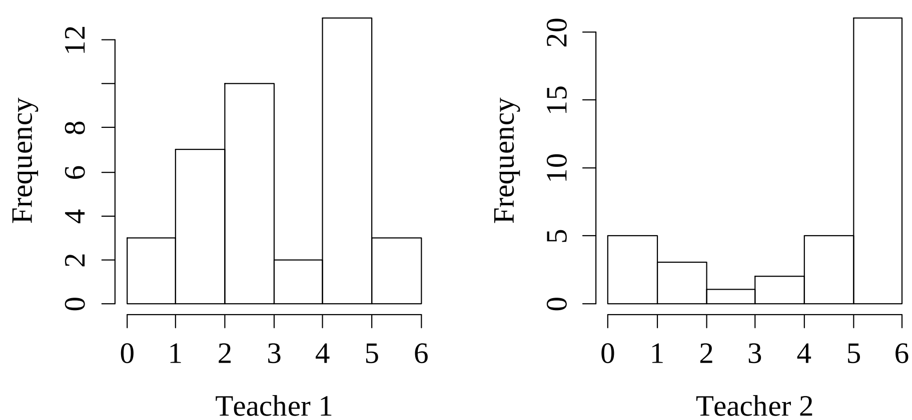


Figure 4-3: **Classroom B89 Teacher Response Histograms**



Analysis proceeded with the creation of three datasets with 23 participants each, seeded from the full dataset of 44 participants. Where multiple teacher scores were available for a classroom, individuals were selected based on job title. The first dataset (**`survdat1`**) was composed of Lead Teachers to the greatest extent possible and contained 5 Associate Teachers. The second dataset (**`survdat2)`** contained mostly Associate Teachers with 8 Lead Teachers. The third dataset (**`survdat3)`** included Teacher's Aides to the greatest extent possible, with the second choice being Lead Teacher. This dataset contained 11 Teacher's Aides, 10 Lead Teachers and 2 Associate Teachers. *Figure B-1*,

Figure B-2 and *Figure B-3* in Appendix B show the distribution of each teacher's responses in each of the datasets. Due to the procedure for creating these datasets, if only one teacher responded for a classroom, that teacher's responses are used in all three datasets.

The Lead Teacher dataset (**`survdat1`**) was selected for the remaining data analysis. Compared to the other two datasets, it consistently had the highest internal consistency for items grouped by domain. Based on exploration of variance within classrooms described above, the Lead Teachers also tended to provide responses with more normal distributions. The compromise in selecting primarily Lead Teachers is that variance at the individual level is lower, possibly obscuring mediating relationships related to experience, age or organizational satisfaction.

The Cronbach's alpha of the 38 IEQ items is 0.92. A simplified correlation table of all 45 items is provided in *Figure B-4* of Appendix B. As described in Chapter 3, the survey items are grouped theoretically in the domains of size, view, acoustic, thermal, lighting, air quality, furnishings, cleaning and overall. The results sections below provide detailed analysis on how the items were selected to form composite scores for each domain. Table 4-1 presents the final composite scores used for data analysis and the reliability of the items combined to form the composite. A single item at the end of the survey, **`ieqoverall`**, serves as a measure of self-reported overall IEQ satisfaction. The composite scores are also combined to create an omnibus IEQ measure (**`ieqT`**) and an IEQ score for just the sensory domains of acoustics, lighting, thermal comfort and air quality (**`ieq.sensory`**). The variance in composite scores explained at the school level is included in Table 4-1 for interpretation of results and to describe the variance that remains to be explained by predictors in the physical environment.

Because scaled and centered scores are used throughout the analysis, Table B-1 in Appendix B presents raw scores for each composite to provide an understanding of absolute differences in teacher responses. Both Table 4-1 and Table B-1 show differences between schools in teacher satisfaction with classroom size, acoustics, natural light, furniture and cleaning.

Several of the composite scores shown in Table 4-1 are correlated. Table 4-2 provides the Pearson's correlations. Because all composites are self-reported perceptions of IEQ, these relationships are less valuable for understanding relationship in the physical environment than they are for investigating latent factors in the perception of IEQ.

Some of the significant correlations in the sensory domains are plotted in *Figure 4-4* to illustrate the level of agreement between items for teachers and to qualify the statistical tests for the small and convenient sample. As suggested by the literature, there is a correlation between the perception of thermal comfort and air quality. However, the other correlations, such as that between air quality and acoustics, were not anticipated. Also of note is that satisfaction in the sensory domains does not predict overall satisfaction. A common correlation with overall IEQ would help explain the inter-sensory correlations that are otherwise challenging to interpret.

Table 4-1: ***Composite Scores and Constituent Items***

Composite (# of items)	Survey Items	Cronbach's Alpha (α)	Variance Attributable to School
sizesat (2)	~~**sizepersonal**~~, **sizechild**, **sizeinterfere**	0.83	18%*
viewsat (3)	**viewcoworker**, **viewprivacy**, **viewnature**, ~~**viewinterfere**~~	0.74	11%
accsat2 (3)	**bnlsat**, **stcsat**, **claritysat**, ~~**accprob**~~, ~~**accinterfere**~~	0.66	17%*
thermsat (4)	~~**tempcontrol**~~, **tempsat**, **tempchild**, **tempprob**, **tempinterfere**	0.84	2%
airtot (3)	**airsat**, **airprob**, **airinterfere**	0.73	0%
lighttot (2)	~~**lightcontrol**~~, **lightsat**, **lightprob**	0.19	5%
naturaltot (2)	**naturalsat**, **naturalprob**, ~~**lightinterfere**~~	0.53	19%*
furntot (6)	**furnadult**, **furnchild**, **furnadjust**, **furnlayout**, **finishes**, **furninterefere**	0.87	21%*
cleantot (5)	**cleanorg**, **cleanservice**, **cleandisplay**,**cleanprob**, **cleaninterfere**	0.85	29%*
orgsat (7)	**enjoy**, **team**, **invests**, **paid**, **purpose**, **quit**, **friends**	0.80	1%
ieqoverall (1)	**ieqoverall**	N/A	0%
ieq.sensory (5)	**accsat2**, **thermsat**, **airtot**, **lighttot**, **naturaltot**	0.67	4%
ieqT (9)	**sizesat**, **viewsat**, **accsat2**, **thermsat**, **airtot**, **lighttot**, **naturaltot**, **furntot**, **cleantot**	0.84	16%

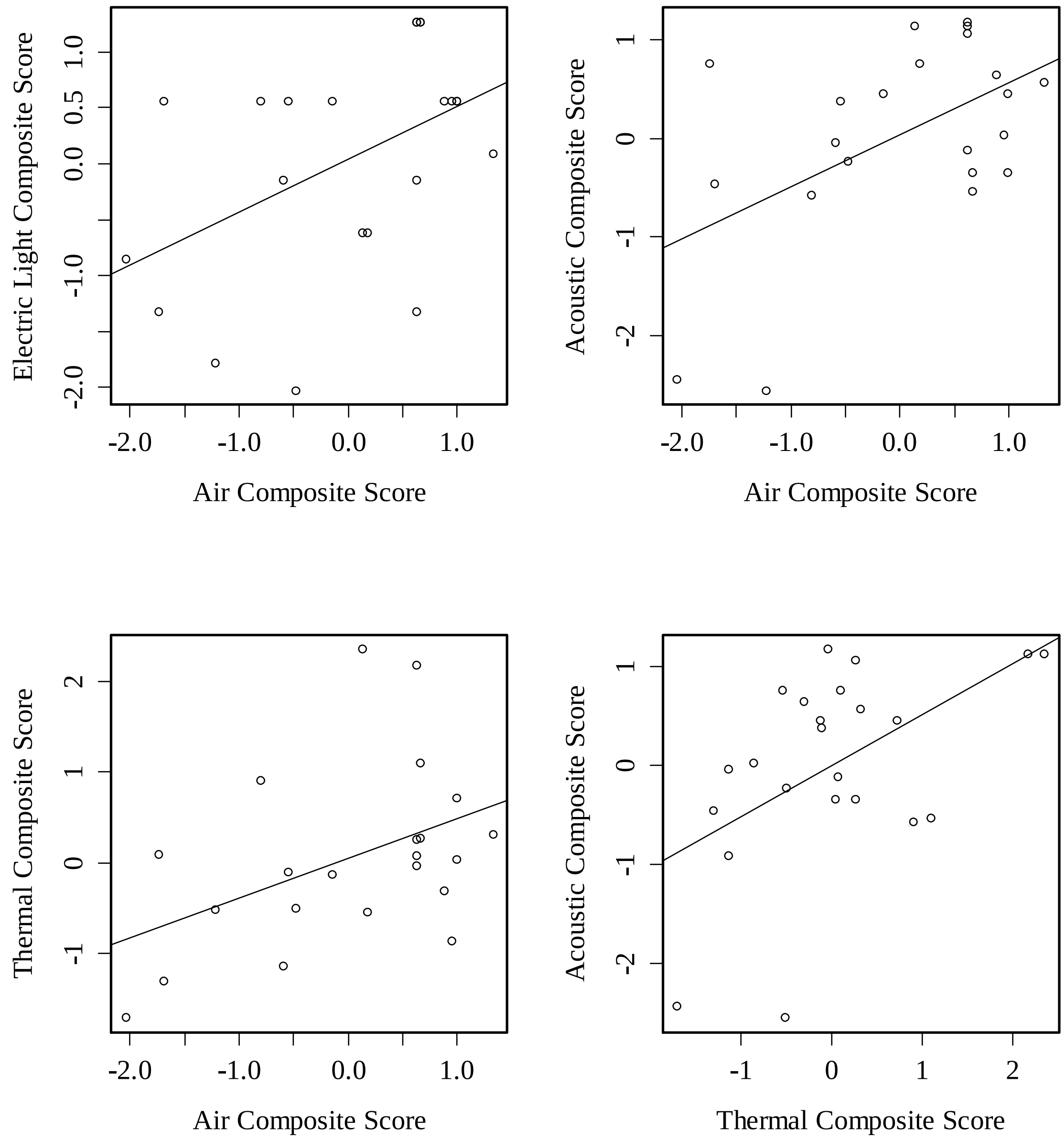
* significant at the $p < 0.05$ level

Table 4-2: ***Composite Score Pearson's Correlations***

	Composite	1	2	3	4	5	6	7	8	9	10
1	**sizesat**	-									
2	**viewsat**	0.54**	-								
3	**accsat2**	0.50*	0.58**	-							
4	**thermsat**	0.22	0.28	0.51*	-						
5	**airtot**	0.09	0.37	0.53*	0.44*	-					
6	**lighttot**	-0.01	0.29	0.30	0.31	0.47*	-				
7	**naturaltot**	0.59**	0.55**	0.33	-0.01	-0.04	0.08	-			
8	**furntot**	0.47*	0.65***	0.61**	0.38	0.43*	0.25	0.35	-		
9	**cleantot**	0.66***	0.60**	0.45*	0.16	0.28	0.02	0.47*	0.74***	-	
10	**orgsat**	0.35	0.32	0.13	-0.32	-0.12	0.24	0.42*	0.20	0.30	-
11	**ieqoverall**	0.53**	0.52*	0.22	0.07	0.20	0.26	0.26	0.18	0.49*	0.38

* $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$

***Figure 4-4*: Sensory Composite Score Agreement**



To explore further the composite interrelationships, Table 4-3 is presented in a graphical format that includes the number of significant correlations. For this purpose, the significance level is $p < 0.1$. As expected, the two overall IEQ composite items show the greatest number of relationships to other composite scores. In addition, satisfaction with classroom size, views and furnishings are related strongly to the other composites.

Satisfaction with electric lighting and organizational satisfaction share the fewest relationships with the other composite items.

Table 4-3: ***Composite Score Spearman's Correlations***

Composite Score		1	2	3	4	5	6	7	8	9	10	11	12	13	Count
1	**sizesat**		$p < 0.001$	$p < 0.1$				$p < 0.01$	$p < 0.01$	$p < 0.001$	$p < 0.1$	$p < 0.1$	$p < 0.1$	$p < 0.001$	9
2	**viewsat**	$p < 0.001$		$p < 0.1$				$p < 0.001$	$p < 0.01$	$p < 0.01$		$p < 0.01$	$p < 0.1$	$p < 0.001$	8
3	**accsat2**	$p < 0.1$	$p < 0.1$		$p < 0.1$				$p < 0.1$	$p < 0.1$			$p < 0.01$	$p < 0.01$	7
4	**thermsat**			$p < 0.1$		$p < 0.1$	$p < 0.1$		$p < 0.1$				$p < 0.01$	$p < 0.1$	6
5	**airtot**				$p < 0.1$		$p < 0.1$		$p < 0.1$				$p < 0.001$	$p < 0.1$	5
6	**lighttot**				$p < 0.1$	$p < 0.1$							$p < 0.01$		3
7	**naturaltot**	$p < 0.01$	$p < 0.001$							$p < 0.1$	$p < 0.1$	$p < 0.1$	$p < 0.1$	$p < 0.01$	7
8	**furntot**	$p < 0.01$	$p < 0.01$	$p < 0.1$	$p < 0.1$	$p < 0.1$				$p < 0.001$			$p < 0.1$	$p < 0.001$	8
9	**cleantot**	$p < 0.001$	$p < 0.01$	$p < 0.1$				$p < 0.1$	$p < 0.001$			$p < 0.1$		$p < 0.001$	7
10	**orgsat**	$p < 0.1$						$p < 0.1$				$p < 0.1$		$p < 0.1$	4
11	**ieqoverall**	$p < 0.1$	$p < 0.01$					$p < 0.1$		$p < 0.1$	$p < 0.1$		$p < 0.1$	$p < 0.01$	7
12	**ieq.sensory**	$p < 0.1$	$p < 0.1$	$p < 0.01$	$p < 0.01$	$p < 0.001$	$p < 0.01$	$p < 0.1$	$p < 0.1$			$p < 0.1$		$p < 0.001$	10
13	**ieqT**	$p < 0.001$	$p < 0.001$	$p < 0.01$	$p < 0.1$	$p < 0.1$		$p < 0.01$	$p < 0.001$	$p < 0.001$	$p < 0.1$	$p < 0.01$	$p < 0.001$		11

■ $p < 0.001$ ■ $p < 0.01$ ■ $p < 0.1$

SECTION 4.2 - Organizational Satisfaction Results

Seven survey items measure organizational satisfaction. Although they appear at the end of the survey, the results are provided before the IEQ items because organizational satisfaction is hypothesized to mediate relationships with IEQ. The items are reliable with a Cronbach's alpha of 0.80, and all are retained to form the composite score **`orgsat`** for use in analysis. A summary of the items and correlation is provided in Table 4-4.

Table 4-4: ***Pearson's Correlations of Organizational Satisfaction Items***

Survey Item Summary		Variable	1	2	3	4	5	6
I enjoy my work.	1	**`enjoy`**	-					
My team works well together.	2	**`team`**	0.33	-				
My employer invests to make me more successful.	3	**`invests`**	0.54**	0.11	-			
I am paid fairly.	4	**`paid`**	0.38	0.05	0.52*	-		
I understand the purpose of my organization.	5	**`purpose`**	0.51*	0.32	0.31	0.46	-	
It would take a lot to get me to leave this job.	6	**`quit`**	0.45*	0.30	0.56**	0.30	0.40	-
I have a trusting relationship with one or more co-workers.	7	**`friends`**	0.52*	0.52*	0.48*	0.10	0.45*	0.47

Organizational satisfaction is correlated with satisfaction with natural light as shown in Table 4-2. It is a moderate predictor of the overall IEQ item. As discussed in more detail below, **`orgsat`** moderates other relationships between the physical environment and satisfaction, although no features of the physical environment predict organizational satisfaction. Other individual level characteristics, such as age and length of time assigned to same classroom, did not significantly mediate relationships between composite scores and the physical environment.

SECTION 4.3 - Room Size Results

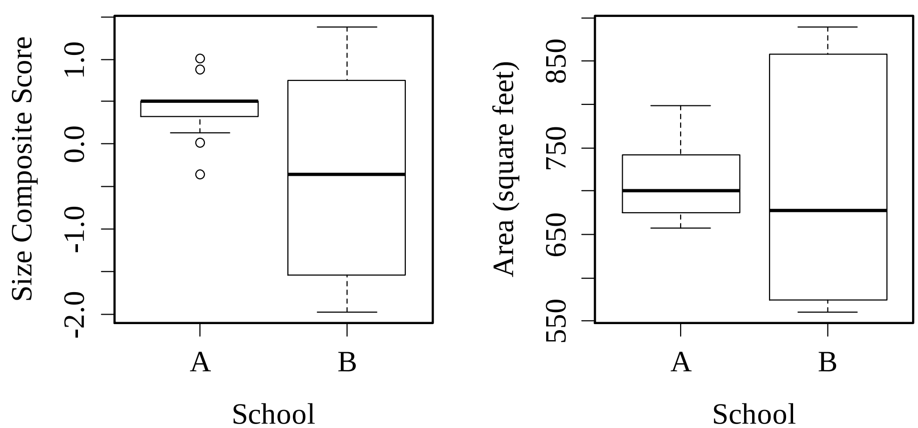
4.3.1- Survey results. Three items on the survey targeted satisfaction with room size. These were **`size personal`**, **`sizechild`** and **`sizeinterfere`**. The latter two items were well correlated with a Cronbach's alpha of 0.83 and combined to form the composite score **`sizesat`**. The items and correlations are provided in Table 4-5. Satisfaction with room size varies between schools, as shown in the distribution of scores in *Figure 4-5* and the means provided in Appendix B, Table B-1. Teachers at School A were more satisfied with their room size by 1.0 points on the 6-point scale.

Table 4-5: ***Pearson's Correlations of Size Items***

Survey Item Summary		Variable	1	2	3
How satisfied are you with the amount of space available for your use and storage?	1	**sizepersonal**	-		
How satisfied are you with the amount of space available for children?	2	**sizechild**	0.53 ***	-	
Does the classroom size interfere with your ability to do your job?	3	**sizeinterfere**	0.39	0.73 ***	-

4.3.2- Measurement results. Floor area is the only variable in the study that is hypothesized to impact teachers' satisfaction with classroom size. The average area is about 711 square feet at both schools, as shown in Table A-1, although the deviation at School A is 3 times larger than the deviation at School B. This relationship is illustrated in *Figure 4-5*.

Figure 4-5**: Size Composite Score and Area by School**



4.3.3- Findings. Data analysis shows that floor area is a good predictor of satisfaction with classroom size. The statistical tests with significant results are listed in Table B-2. When the size composite score was regressed onto `school`, `area` and interaction `schoolXarea`, both `school` (p = 0.029) and the interaction term (p = 0.053) were moderate predictors, while `area` was not (p = 0.914). The analysis also shows area is significantly more predictive of teacher satisfaction at School B than at School A, as well as in classrooms with younger children. When the interaction term is omitted from the model, area is a significant predictor (p = 0.000) along with school (p = 0.004). One interpretation of the data is that teachers at School B are dissatisfied with small classrooms for infants (Classroom Type 0). The overall relationship between area and satisfaction as well as the school interaction is illustrated in *Figure 4-6*.

***Figure 4-6*: Area and Size Composite Score Overall and by School**

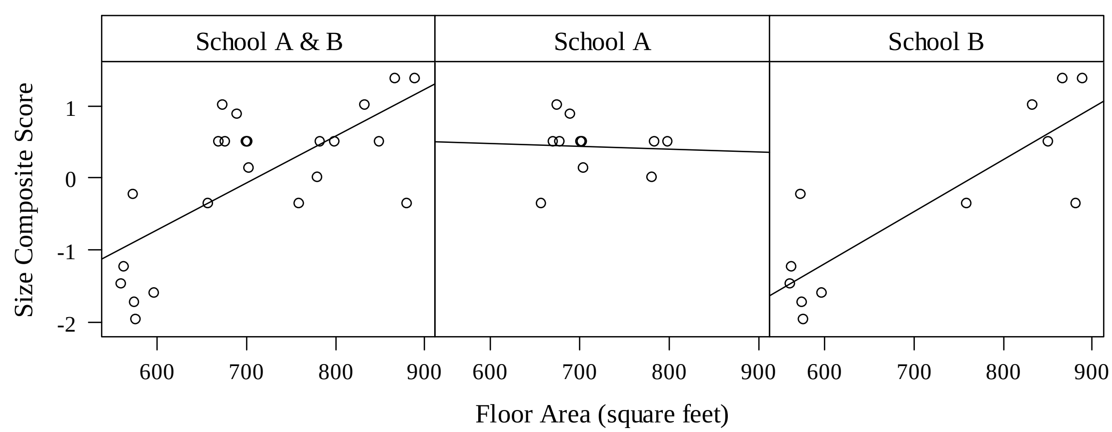
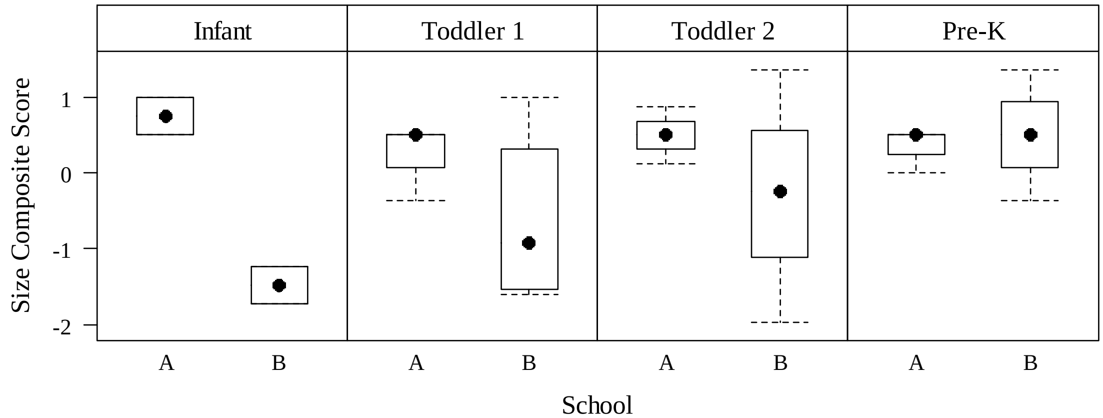


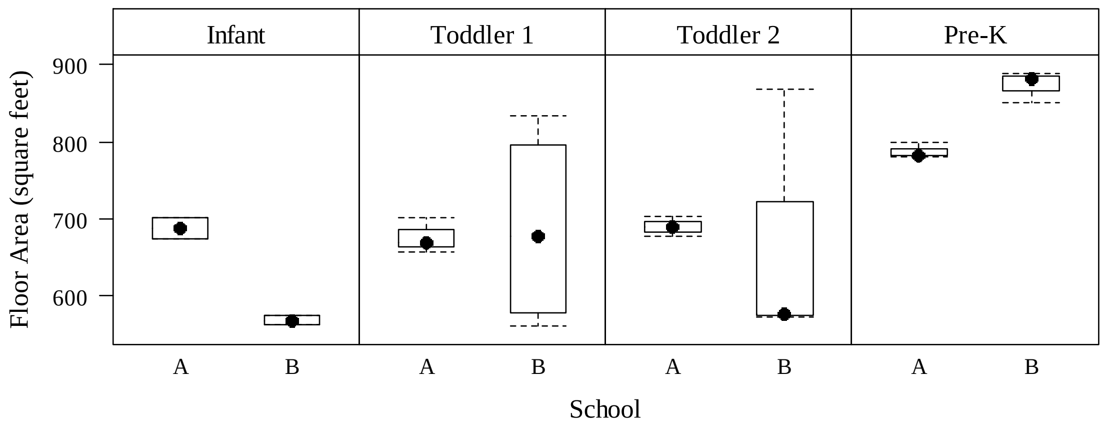
Figure 4-7 shows the interaction of area and the size composite score across classrom types. When the size composite score is regressed onto classroom type (**`crtype`**), area and interaction **`area`**X**`crtype`**, area is a good predictor with classroom

type and the interaction, both being moderate predictors. This may be explained by the fact that older children at School B have larger classrooms.

When the size composite score is regressed onto unoccupied background noise level (**bnllow**) and **school**, **bnllow** is significant (*p* = 0.018), with each A-weighted sound pressure level (dB) increase lowering satisfaction levels by 0.17 standard deviations. When the composite score **sizesat** is regressed onto **bnllow, school** and the interaction term **bnllow**X**school**, the interaction is a moderate predictor (*p* = .068), and **bnllow** is not significant. These relationships are plotted in *Figure 4-8*. When the size composite score is regressed onto **bnllow**, classroom type (**crtype**) and the interaction **bnllow**X**crtype**, **bnllow** is significant (*p* = 0.004), and **crtype** and the interaction are both moderate predictors ($p < 0.10$). This relationship is shown in *Figure 4-9*, and all regression tests are listed in Table B-2 of Appendix B. This finding suggests that teachers may be more sensitive to background noise in classrooms with younger children. Reverberation time is also a moderate predictor of size satisfaction scores, although reverberation time is strongly correlated with area, which is hypothesized as a confound that explains this result. Classroom type did not predict the size composite score.

***Figure 4-7*: Area and Size Composite Score by Classroom Type**





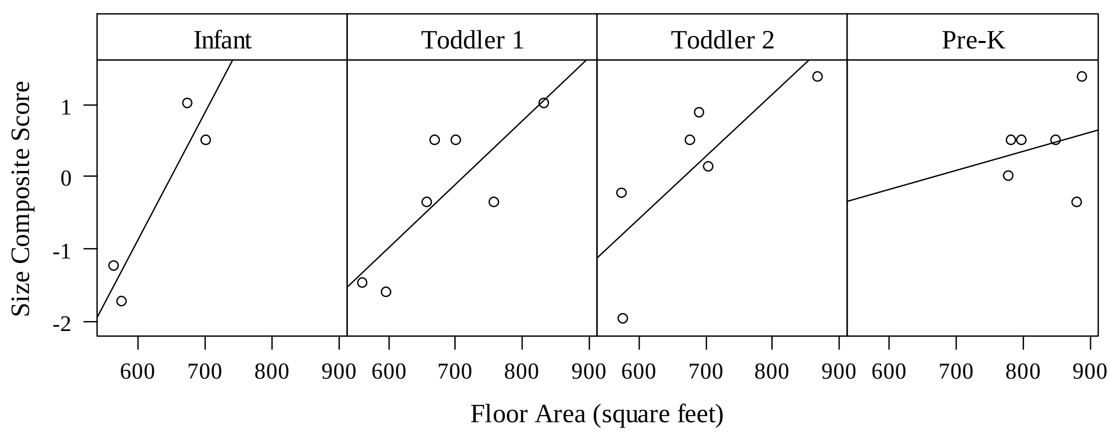


***Figure 4-8*: Size Composite Score by BNL**

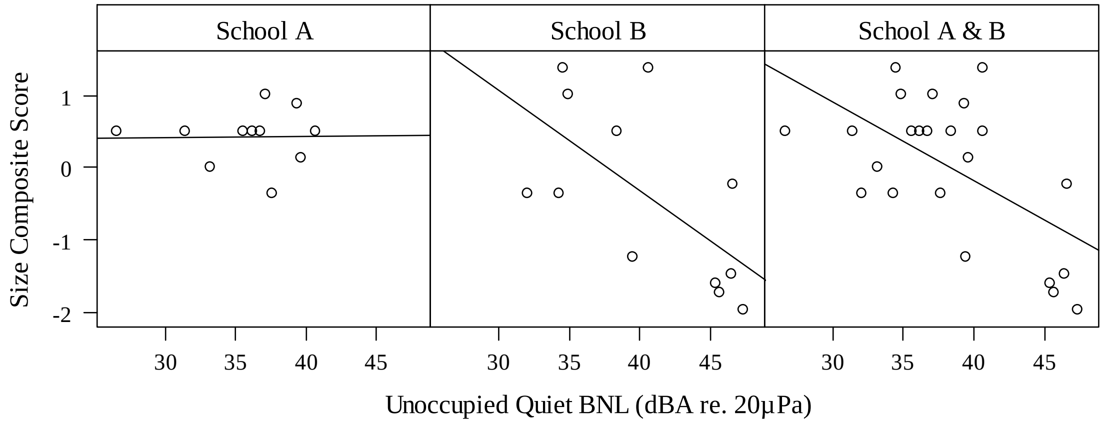
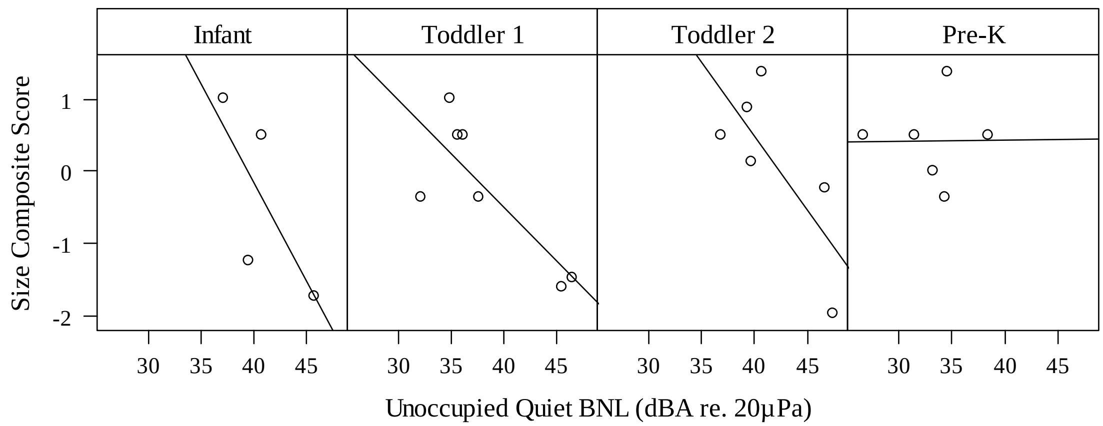


***Figure 4-9*: Size Composite Score by BNL and Classroom Type**



SECTION 4.4 - View Results

4.4.1- Survey results. Four items on the survey asked teachers to report satisfaction with views related to their classroom space. Three items were selected to increase Cronbach's alpha from 0.70 to 0.74, creating the composite score **`viewsat`**. The items used are **`viewcoworker`**, **`viewprivacy`** and **`viewnature`**. The view composite score is not different between schools, with larger variance at School B, as indicated in *Figure 4-10*.

Table 4-6: ***Pearson's Correlations of View Items***

Survey Item Summary		Variable	1	2	3	4
How satised are you with the ability to … see your co-workers?	1	**`viewcoworker`**	-			
How satisfied are you with the privacy of your classroom …?	2	**`viewprivacy`**	0.28	-		
How satisfied are you with the quality of view to … nature?	3	**`viewnature`**	0.50 *	0.66 **	-	
Do the classroom views interfere with your ability to do your job?	4	**`viewinterfere`**	0.52 *	0.25	0.08	-

4.4.2- Measurement results. The average classroom illuminance ratio was about 2.5 and did not vary by school, as shown in Table A-4 of Appendix A. The standard deviation was 0.38. Despite large differences in lighting power density and illuminance levels between schools, the ratio of the highest and lowest of four illuminance measurements was relatively consistent.

4.4.3- Findings. With the view composite score regressed onto the ratio between average high and average low illuminance **`(illumratio)`** and **`school`**, **`illumratio`** is a good predictor ($p = 0.034$), and **`school`** is a moderate predictor ($p < 0.10$). This relationship is plotted in *Figure 4-11*. The interaction **`illumratio`**X**`school`** was not significant, and greater ratios of high to low illuminance corresponded to higher composite view scores. As listed in Table 4-2, the composite score **`viewsat`** **`(viewcoworker`**, **`viewprivacy`** and **`viewnature)`** is correlated to the overall IEQ item, also plotted in *Figure 4-10*.

***Figure 4-10*: View Composite Score by School and Item** `ieqoverall`

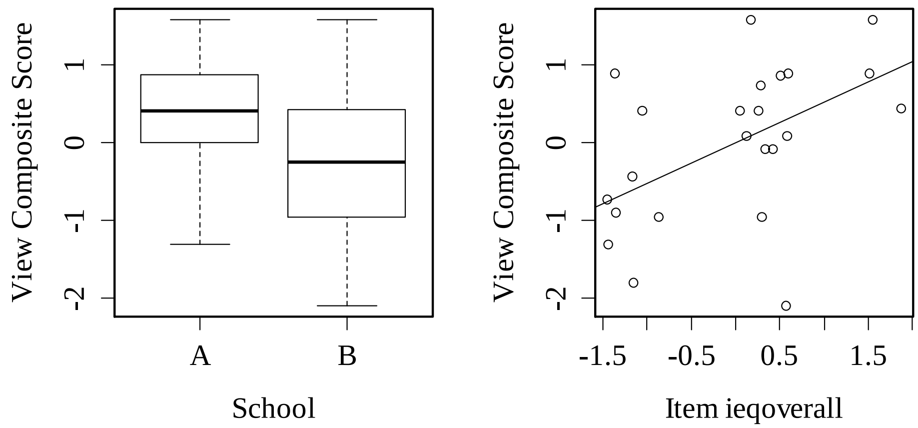
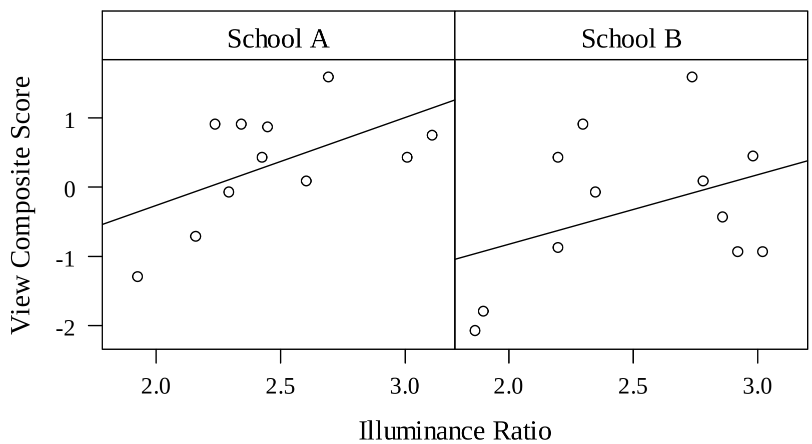


***Figure 4-11*: View Composite Score by Illuminance Ratio**



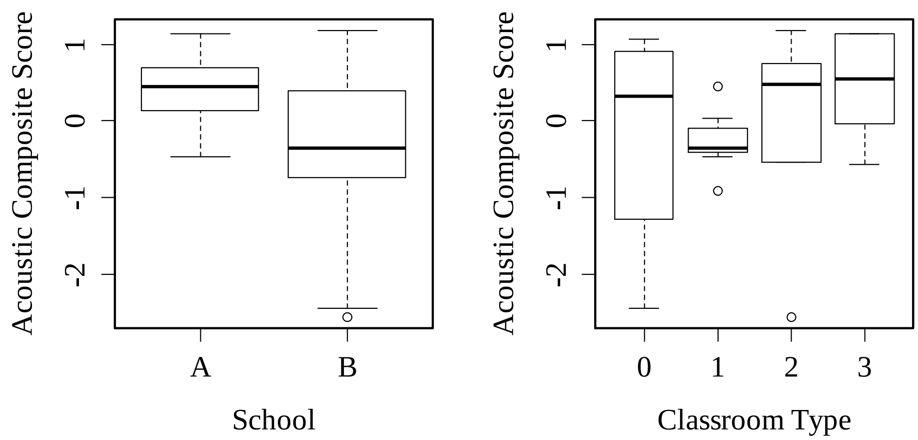
SECTION 4.5 - Acoustic Results

4.5.1- Survey results. Five items are coded on the survey in the acoustic domain as described in Table 3-3. Score correlations are presented in Table 4-7. The first three items (**`bnlsat`**, **`stcsat`** and **`claritysat)`** create the composite acoustic score (**`accsat2`**) that, together, have a Cronbach's alpha of 0.66. A broad composite with all five items also was tested with similar findings, generally having lower significance. Following these preliminary tests, the three-item composite was used for model comparisons. Teachers at School A had significantly higher acoustic composite scores than those at School B, as shown in *Figure 4-12* and Table A-3 of Appendix B.

Table 4-7: ***Pearson's Correlations of Acoustic Outcome Variables***

Survey Item Summary	Variable	1	2	3	4	5
How satisfied are you with the sound level in your classroom?	1 **bnlsat**	-				
How satisfied are you with the ability to keep noise from other spaces out…?	2 **stcsat**	0.69 ***	-			
How satisfied are you with the ability for the children to understand you…?	3 **claritysat**	0.39	0.10	-		
Which of the following create noise problems…? [inverted scale]	4 **accprob**	0.51 *	0.43 *	0.20	-	
Do the acoustics interfere with your ability to do your job?	5 **acc-interfere**	0.58 **	0.16	0.21	0.44 *	-

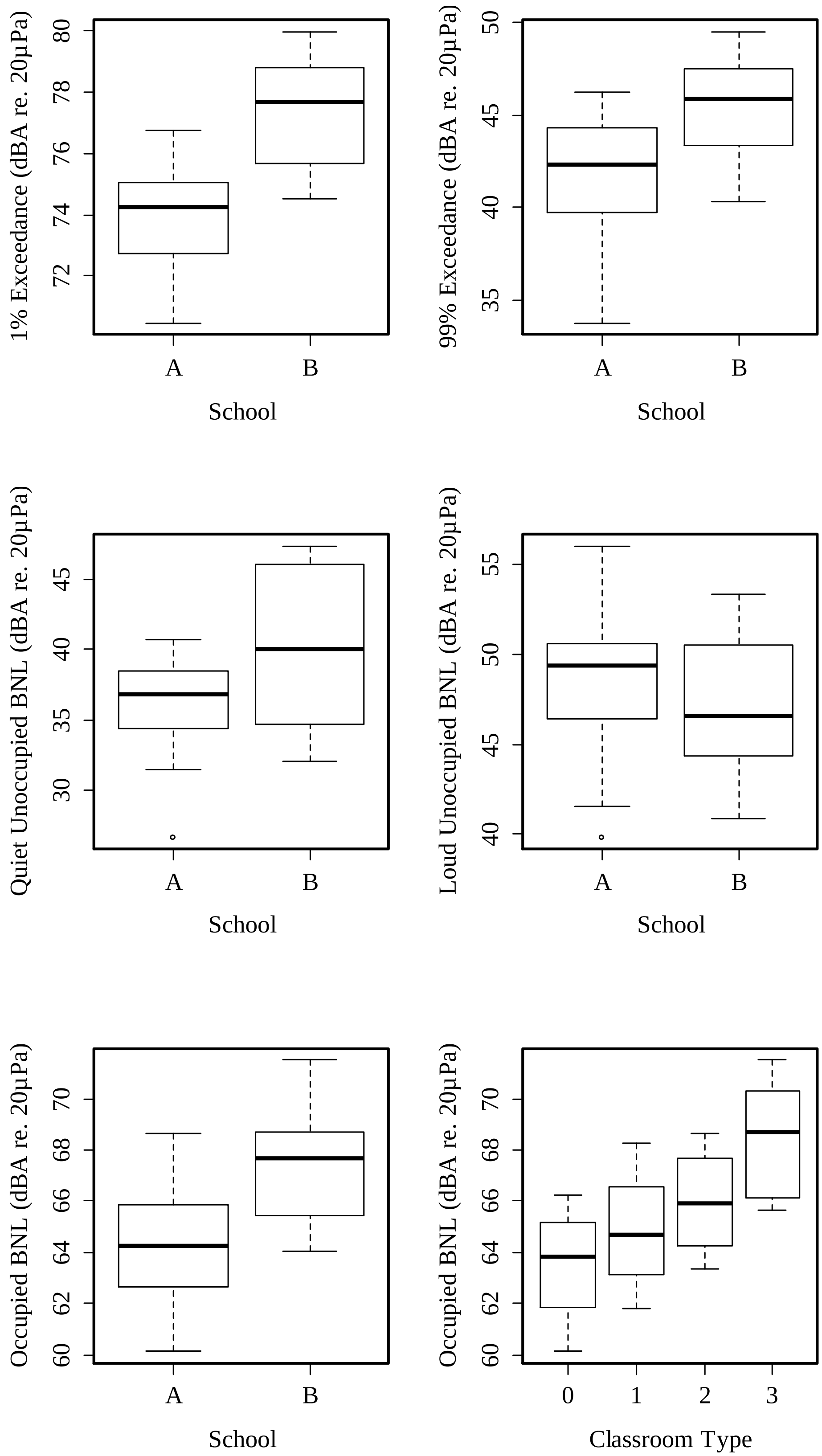
Figure 4-12**: Composite Acoustic Score by School and Classroom Type**



4.5.2- Measurement results. Table A-3 in Appendix A summarizes the acoustical measurements in classrooms. The average reverberation time was 0.43 seconds and exhibited low variance across rooms. The unoccupied A-weighted background noise levels are higher than design recommendations at 38 dB re 20µPa when the mechanical systems were off and 48 dB re 20µPa with heat pumps in heating mode. The average 10-hour occupied A-weighted equivalent sound pressure level was 66 dB re 20µPa, with a 1% exceedance of 76 dB re 20µPa. These levels are acceptable based on safety guidelines.

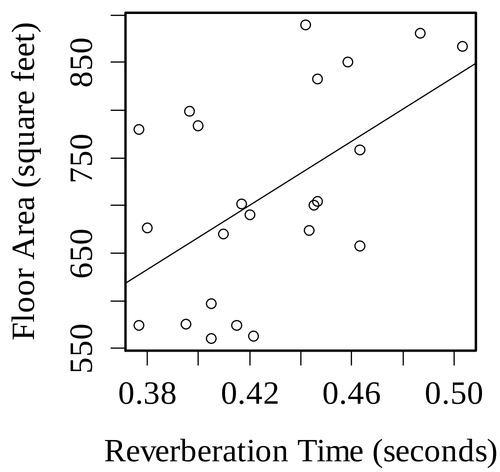
The schools differed significantly in every measure except reverberation time and the loud unoccupied background noise level, **bnlhigh**. *Figure 4-13* shows the data distributions for sound pressure levels. School A is quieter than school B as measured by 1% (**l1**) and 99% (**l99**) exceedance levels, as well as A-weighted, equivalent 10-hour occupied sound pressure level (**laeq10**). Classroom type did not correspond to scores, although rooms with older children had higher occupied sound pressure levels. One notable difference between schools is that, with one exception, all classrooms at School B are conjoined with an adjacent room without acoustic separation. At School A, rooms are used frequently as paired units, although teachers can separate the rooms using double-leaf Dutch doors. There is no significant difference between the schools when the mechanical system is presumably running, as measured by **bnlhigh**. On average, difference between high and low unoccupied background noise levels is a significant 5.6 dB higher at School A than School B.

***Figure 4-13*: Acoustical Measurements Distribution**



4.5.3- Findings. Reverberation time was significantly related to area (p = 0.008), a relationship illustrated in *Figure 4-14*. This presents an inherent confound in the predictor variables that limits inferences from results involving these variables. With this in mind, when the composite acoustic score (accsat2) was regressed onto floor area and school, floor area was a significant predictor (p = 0.015), with school also reaching significance. When the composite score was regressed onto reverberation time and school, reverberation time is a moderate predictor (p = 0.092), and school is a good predictor.

***Figure 4-14*: Floor Area by Reverberation Time**



When the acoustic composite score (**`accsat2`**) was regressed onto unoccupied background noise level and school, **`bnllow`** reached moderate significance ($p < 0.10$). This was also the case for **`bnlhigh.`** When the composite score was regressed onto relative humidity and school, relative humidity is a significant predictor ($p = 0.014$), with school being a moderate predictor ($p < 0.10$). Higher moisture correlated with higher acoustic composite scores. Relative humidity was also significant when included with classroom type as a regressor of composite score. Relative humidity was also a moderate predictor of the five-item composite acoustic score (`accsat1`) in a model with school included as a regressor. The consistency of this finding suggests that the domains of thermal comfort and acoustical satisfaction may be interrelated in occupant perception of IEQ. This is supported further by the correlation of the thermal comfort composite score with the acoustic composite score, as described in *Figure 4-4* and Table 4-2.

***Figure 4-15*: Acoustic Composite Score by Quiet Unoccupied BNL**

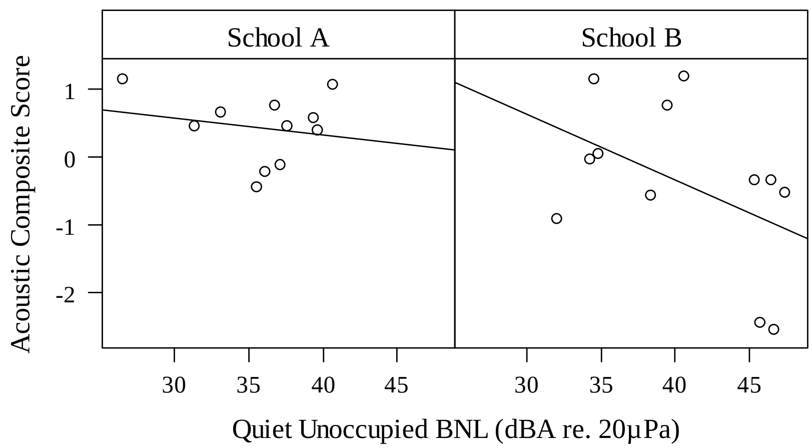
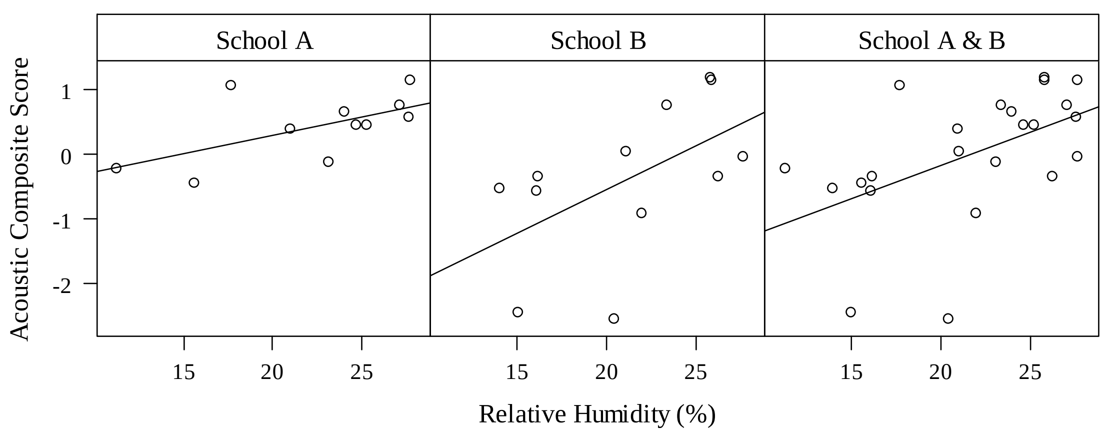
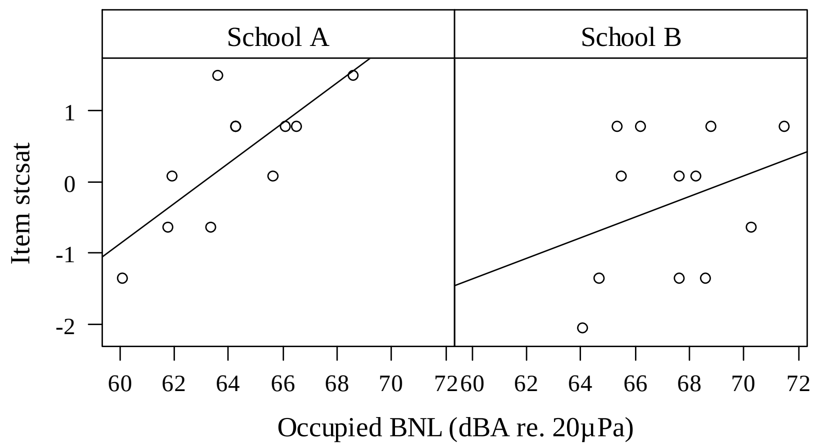


***Figure 4-16*: Acoustic Composite Score by Relative Humidity**



Occupied sound pressure level did not predict the composite acoustic score, although it did predict the item **stcsat** (satisfaction with the ability to keep out noise from other spaces) as a regressor with **school** (*p* = 0.014). This relationship is suggestive at School A, as illustrated in *Figure 4-17*. When **stcsat** was regressed onto **laeq10 (**A-weighted, equivalent 10-hour occupied sound pressure level), **school** and **laeq10**X**school**, the interaction of school and sound pressure level was not significant.

Figure 4-17: **Item stcsat by Occupied BNL Within School**



SECTION 4.6 - Temperature Results

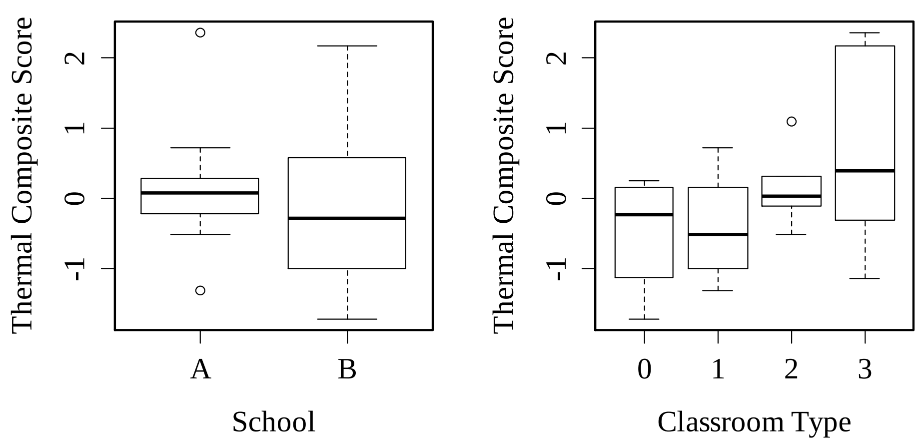
4.6.1- Survey results. The five items targeting occupant thermal comfort combined into the **thermsat** composite (**tempsat**, **tempchild**, **tempprob** and **tempinterfere)**, with the exclusion of **tempcontrol**. The four items exhibit internal reliability with a Cronbach's alpha of 0.84, an increase from the value of 0.76 for all five items. The item correlations are presented in Table 4-8.

The composite score does not vary by school but does vary by **crtype,** classroom type, (*p*=0.034), as shown in *Figure 4-18*. When thermal composite scores were regressed onto classroom type and school, classroom type remained a significant predictor. When thermal composite scores were regressed onto classroom type, school and the interaction **`crtype`**X**`school`**, the interaction was not significant. This may be due to a relatively strong trend in School B of greater thermal satisfaction reported in classrooms with older children. This is represented in *Figure 4-19*.

Table 4-8: ***Pearson's Correlations of Thermal Outcome Variables***

Survey Item Summary		Variable	1	2	3	4	5
Which of the following can you personally control…?	1	**`tempcontrol`**	-				
How satisfied are you with the temperature for your comfort…?	2	**`tempsat`**	0.02	-			
How satisfied are you with the temp. for children's comfort…?	3	**`tempchild`**	0.08	0.53 ***	-		
Check all that apply about the temperature…: [inverted scale]	4	**`tempprob`**	-0.10	0.62 **	0.60 **	-	
Does the temperature interfere with your ability to do your job?	5	**`tempinterfere`**	0.00	0.54 **	0.50 *	0.50 *	-

Figure 4-18: **Thermal Composite Score by School and Classroom Type**



4.6.2- Measurement results. Temperature and relative humidity were relatively consistent across classrooms at both schools. Table A-2 in Appendix A includes thermal comfort measurements at each classroom and shows that temperature at School B was more variable than at School A. This may be related in the distribution of thermal composite scores between schools shown in Figure *4-18* although, as noted above, there was not a significant difference in the score means between the schools.

4.6.3- Findings. Average occupied temperature did not predict the thermal composite score, nor did relative humidity, particulate matter or carbon dioxide concentration. While the data for predictors and outcomes both exhibit large variance, there is little difference in the means, and this may explain the lack of a result. Of note is the correspondence of temperature variance with thermal score variance.

***Figure 4-19*: Thermal Composite Scores by Classroom Type Within School**

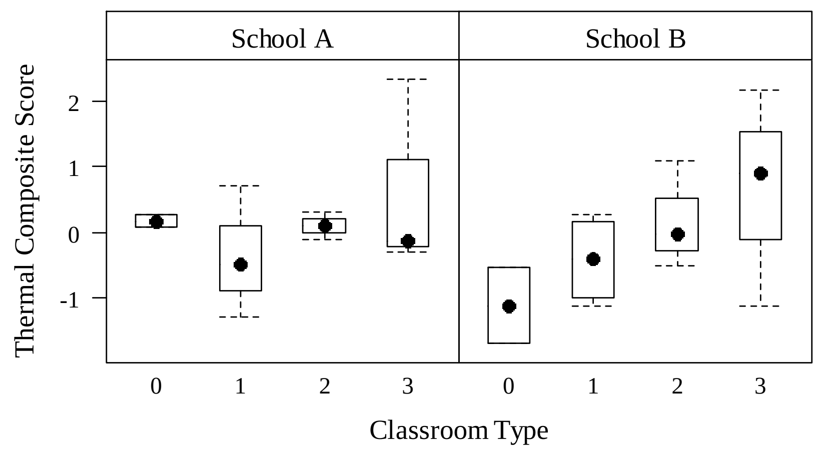


***Figure 4-20*: Temperature by Classroom Type Within School**

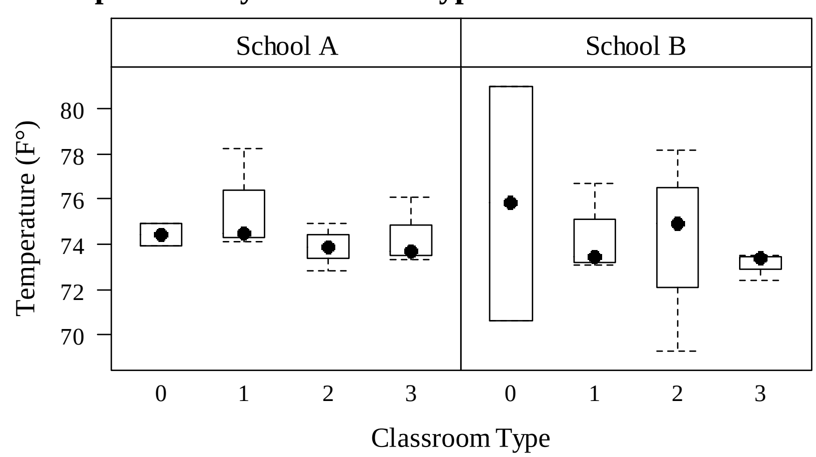
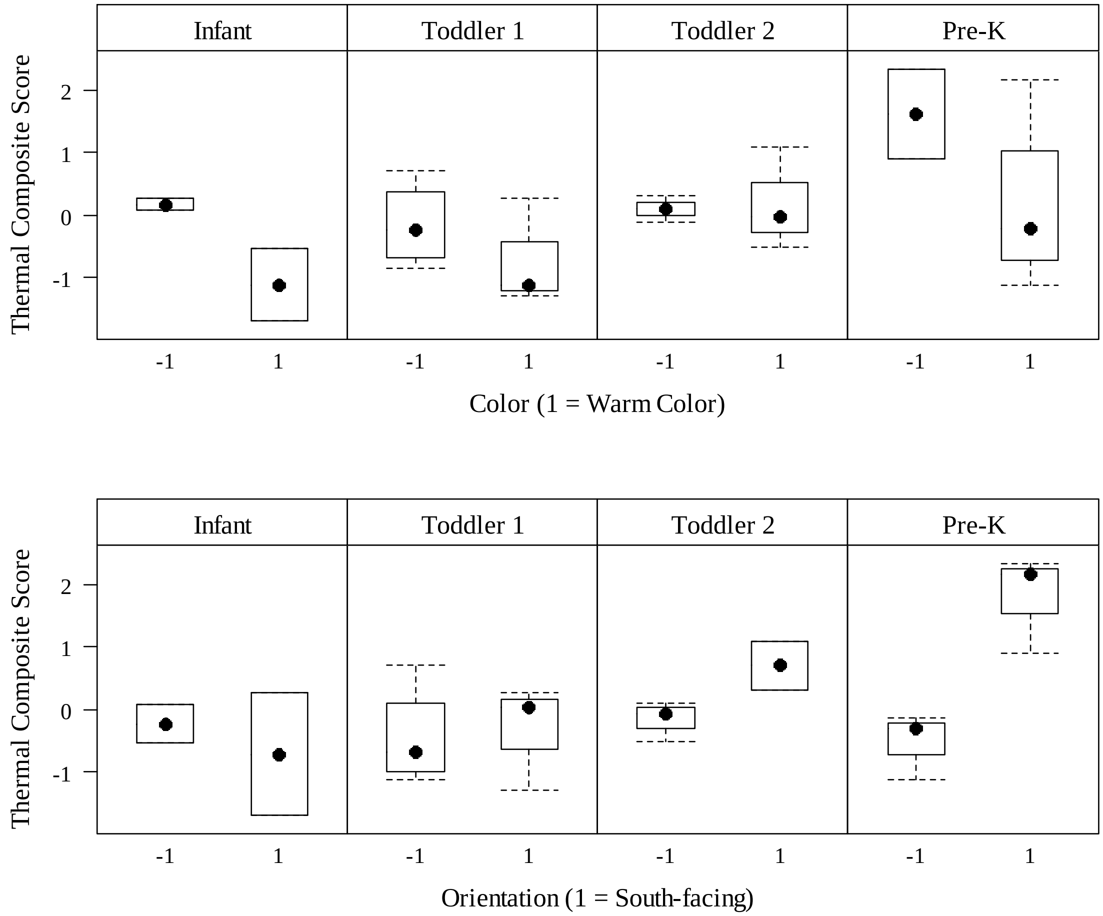


***Figure 4-21*: Thermal Composite Score by Color and Orientation**



When thermal composite scores are regressed onto wall color and classroom type, wall color is a moderate predictor ($p = 0.066$). As illustrated in *Figure 4-21*, cool wall color is associated with higher scores. Thermal scores also varied by classroom orientation. When the composite score was regressed onto orientation and classroom type, the orientation was significant ($p = 0.039$). When the score was instead regressed onto orientation and school, the orientation was a moderate predictor ($p = 0.052$). Teachers in rooms that face southward reported higher thermal composite scores than those in rooms facing other directions. *Figure 4-21* illustrates the relationship by classroom type. These findings are summarized in Appendix B, Table B-2.

SECTION 4.7 - Air Quality Results

4.7.1- Survey results. Three items that target teacher satisfaction with air quality (**airsat**, **airprob** and **airinterfere**) are somewhat reliable with an alpha of 0.73. Together they formed the composite air quality score, **airtot**. Table 4-9 shows the correlations between items on the survey.

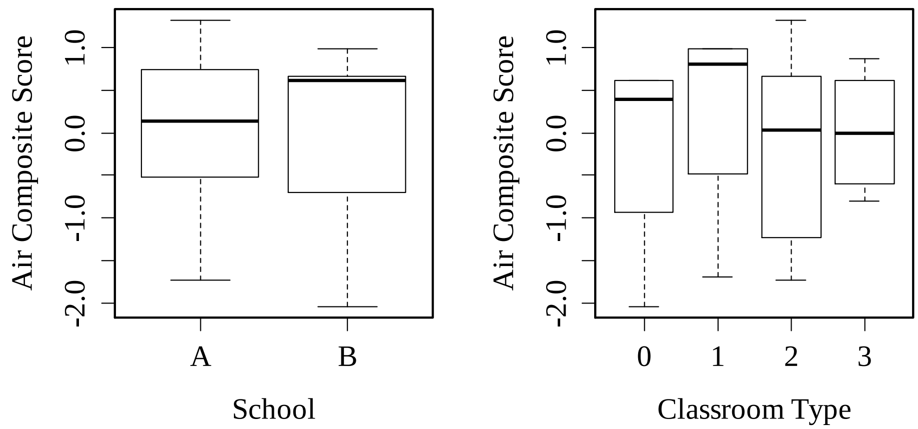
Table 4-9: ***Pearson's Correlations for Air Quality Outcome Items***

Survey Item Summary		Variable	1	2	3
How satisfied are you with the air quality in your classroom?	1	**airsat**	-		
Which of the following contribute to odor problems…? [inverted scale]	2	**airprob**	0.45 *	-	
Does the air quality interfere with your ability to do your job?	3	**airinterfere**	0.65 **	0.42 *	-

Teacher composite scores were similar between schools and classroom type, as illustrated in *Figure 4-22*. The **airinterfere** item (perception that air quality interferes with a teacher's ability to do their job) was predicted moderately by the length of time teachers had been assigned to the same room and was more sensitive to carbon dioxide concentration than was the composite score. However, the full composite represents the respiratory sensory domain as a reliable composite score that shows similar relationships with the physical environment.

Within the survey, teacher satisfaction with air quality was related significantly to several other domains. These are described in the section on survey findings, although the items **bnlsat** (satisfaction with background noise level) and **accsat2** are strongly related, which helps explain the relationship between the composite scores for acoustics and air quality. The correlation suggest that the phrases "sound level (quietness or loudness)" and "air quality" elicit a similar response from occupants and may point to a latent psychological construct.

***Figure 4-22*: Composite Air Score by School and Classroom Type**



4.7.2- Measurement results. Carbon dioxide and particulate matter measured in each classroom are described in Table A-2 of Appendix A. Measurement distributions by classroom type are shown in *Figure 4-23*, and measurements by school are shown in *Figure 4-24*. The levels were within guidelines for quality, with respirable particulate matter ($pm_{2.5}$) averaging 5.15 $\mu g/m^3$ over 10 hours with a maximum 15-minute time weighted exposure of 25.07 $\mu g/m^3$. Inhalable particulate matter (pm_{10}) averaged 25.90 $\mu g/m^3$ over 10 hours with a maximum 15-minute time weighted exposure of 183.94 $\mu g/m^3$. The mean carbon dioxide concentration of rooms was 710.8 ppm over 10 hours, with an average maximum 15-minute time weighted exposure of 850.4 ppm.

Figure 4-23**: Particulate Matter by Classroom Type**

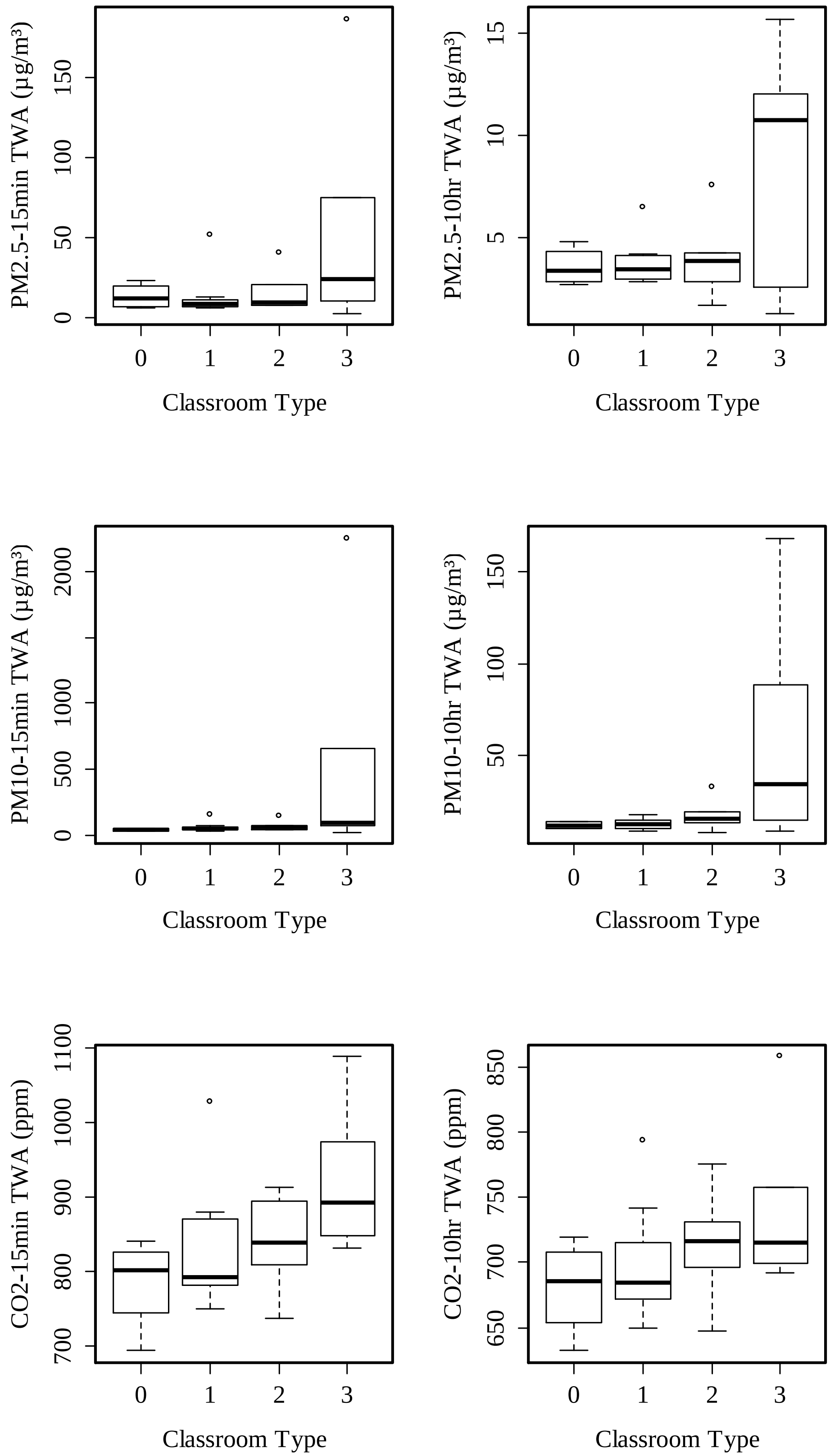
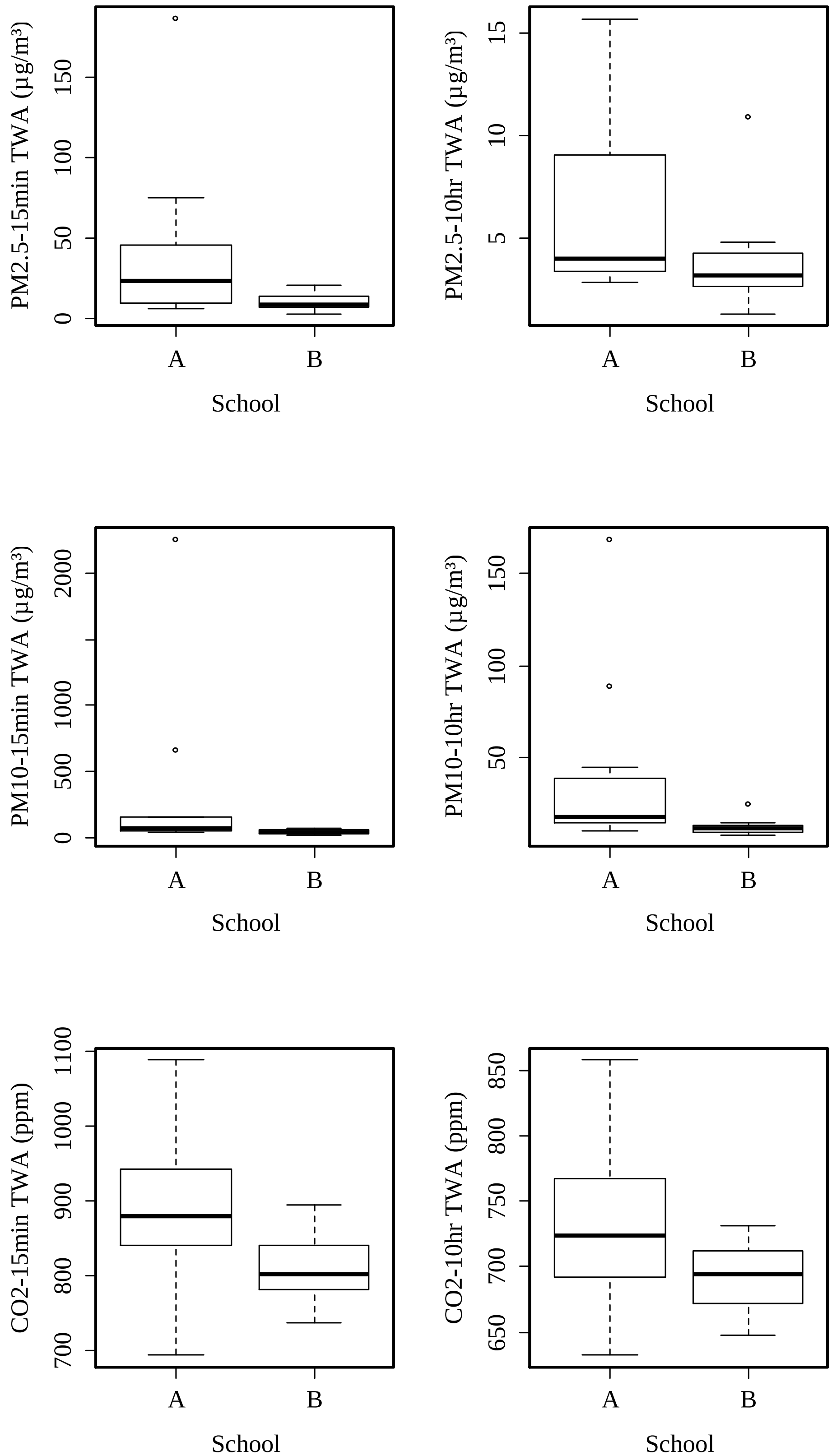


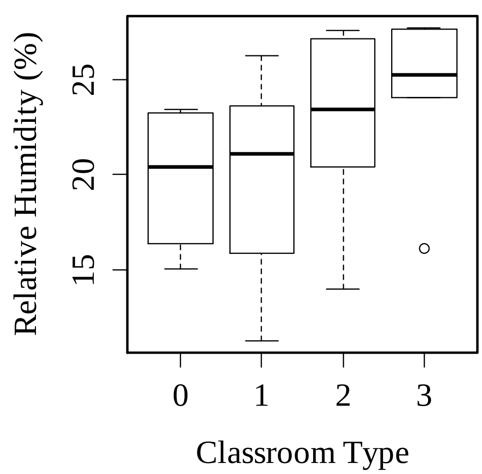
Figure 4-24: **Air Quality Measures by School**



4.7.3- Findings. Physical measures of air quality were related to classroom type. Teacher scores for air quality, therefore, were analyzed specifically by classroom type to discover interactions. Linear models that controlled for this showed no correlation, which suggests that classroom type may not be a serious confound in the dataset for air quality, although the collinear nature of classroom type and air quality make inferences more speculative.

Classrooms with older children had higher relative humidity measurements (*p*=0.075), as illustrated in *Figure 4-25*. Classrooms with older children also exhibited higher levels of particulate matter. Classroom type was correlated significantly with 10-hour particulate matter concentrations and moderately with 15-minute averages. These relationships are shown in *Figure 4-23*. The composite air quality score and the **`airinterfere`** item were not dependent on classroom type.

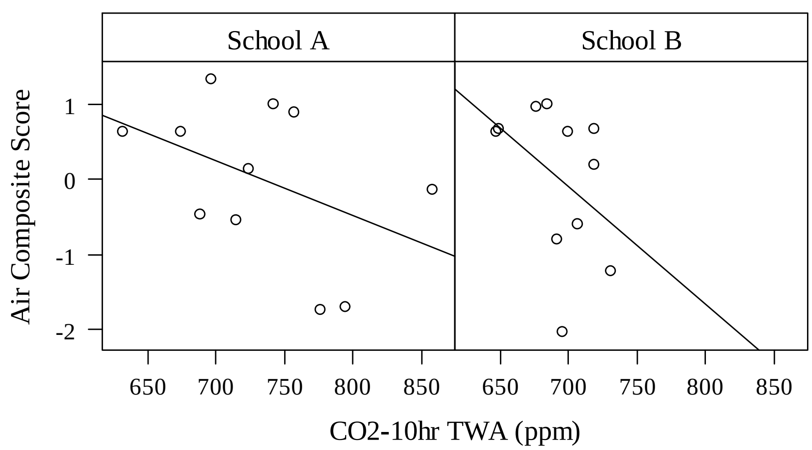
***Figure 4-25*: Relative Humidity by Classroom Type**



Teachers who had been assigned to their classrooms less than 3 months reported higher scores for the **`airinterfere`** item (*p*=0.059). This phenomenon of score elevation with length of assignment also was apparent in the preliminary analysis with 44 teachers and occurred in several other domains of the physical environment. The difference between **airinterfere** and **airtot** is discussed further in Chapter 5 with respect to how the items are worded. The data suggests that the familiarity of a space to occupants may be an important consideration when assessing satisfaction with IEQ.

The composite air quality score (**airtot**) was moderately predicted by carbon dioxide particle concentration, both 10-hour and 15-minute time-weighted averages. Including school as a predictor increases the significance of carbon dioxide concentration as a predictor. The relationship of 10-hour average carbon dioxide (p = 0.069) and school to air composite scores is illustrated in *Figure 4-26*. The **airinterfere** item also was correlated to carbon dioxide concentration, both with and without **school** as a regressor.

***Figure 4-26*: Composite Air Score by CO_2 Concentration (10-Hour)**



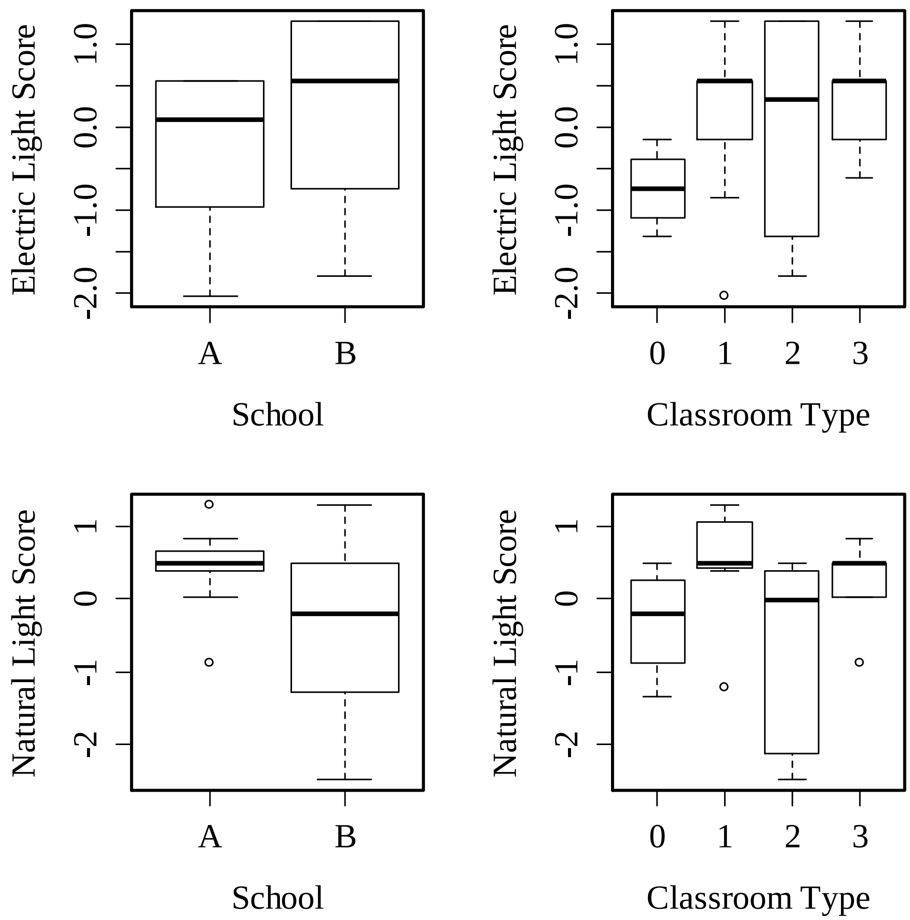
SECTION 4.8 - Lighting Results

4.8.1- Survey results. Survey items related to lighting were not reliable as a group, with a Cronbach's alpha of 0.49 and low correlations between them pairwise as shown in Table 4-10. Based on relationships between lighting outcomes and predictors, the items are hypothesized to reflect two psychological constructs that relate to electric and natural lighting. Therefore, two composite scores are created for the lighting domain: **lighttot** and **naturaltot, respectively**. The variables **lightsat** and **lightprob** formed **lighttot** with a resulting alpha of 0.19. Variables **naturalsat** and **naturalprob** combined into **naturaltot** with an alpha of 0.53. The low number of items for each composite contributes to these low values of alpha. The resulting composite scores are illustrated in *Figure 4-27*.

Table 4-10: ***Pearson's Correlations of Lighting Outcome Items***

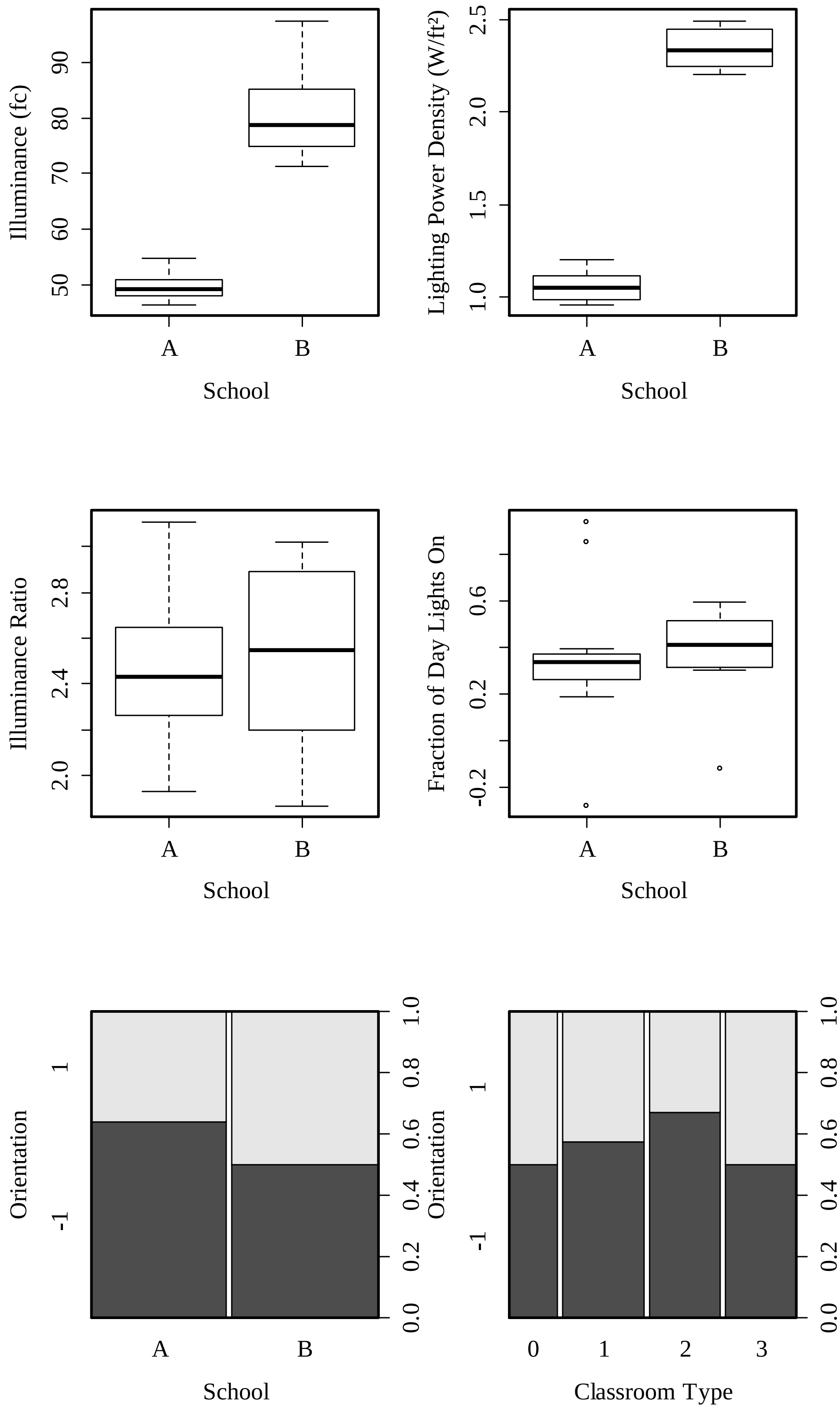
Survey Item Summary		Variable	1	2	3	4	5	6
Which of the following can you personally control…?	1	**lightcontrol**	-					
How satisfied are you with the electric light in your classroom?	2	**Lightsat**	-0.16	-				
Check all that apply about the electric light…: [inverted scale]	3	**lightprob**	-0.29	0.11	-			
How satisfied are you with the daylight… in your classroom?	4	**naturalsat**	0.25	-0.20	0.27	-		
Check all that apply about the daylight…: [inverted scale]	5	**naturalprob**	-0.14	-0.09	0.21	0.36*	-	
Does the lighting interfere with your ability to do your job?	6	**lightinterfere**	0.06	-0.03	-0.05	0.50*	0.54**	-

***Figure 4-27*: Composite Lighting Scores by School and Classroom Type**



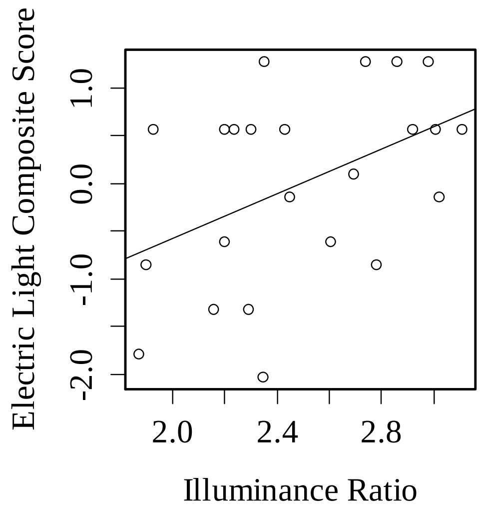
4.8.2- Measurement results. Lighting measures in the physical environment varied significantly between schools but not between classroom types. Electric lighting is predominantly fluorescent tube lamps in both schools, although the lighting power density at School B is higher than at School A. The predominant fixture type at School B is recessed troffers with parabolic lenses. School A uses predominantly volumetric indirect recessed troffers. The classroom lighting measurements are summarized in Table A-4 of Appendix A. *Figure 4-28* represents the lighting measurements by school. The distribution of window orientation, with south facing coded as +1, is also shown by classroom type.

***Figure 4-28*: Lighting Characteristics by School**



4.8.3- Findings. The composite electric lighting score, **`lighttot`**, was regressed onto illuminance ratio, and school with illuminance ratio being a significant predictor (p = 0.036). Illuminance ratio was also significant without school included as a regressor. This relationship is illustrated in *Figure 4-29*. There were no other significant relationships between the electric lighting composite score and the physical environment.

***Figure 4-29*: Composite Lighting Score by Illuminance Ratio**



Natural light composite scores differ by school (p = 0.040), with teachers at School A being more satisfied. Floor area and school significantly predict composite natural light satisfaction; however, when the interaction for school and area is included, area is not a significant predictor. The distribution of scores precludes suggestive findings on area and school as predictors of satisfaction with natural light. This complicated relationship is shown in *Figure 4-30*.

When the natural lighting composite score, **`naturaltot`**, is regressed onto illuminance and school, illuminance is a significant predictor (p = 0.004). However, illuminance levels do not predict satisfaction without school, which is also a significant predictor (p = 0.001). The bimodal dataset is depicted in *Figure 4-31* of illuminance levels and satisfaction for each school.

***Figure 4-30*: Natural Light Composite Score by Area Within School**

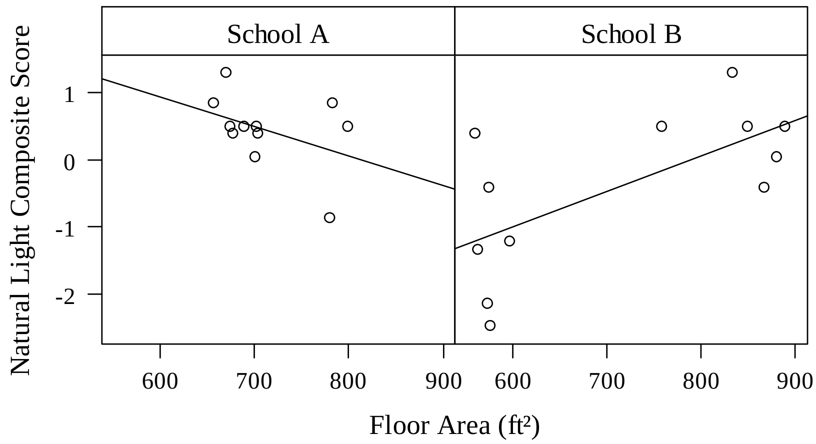
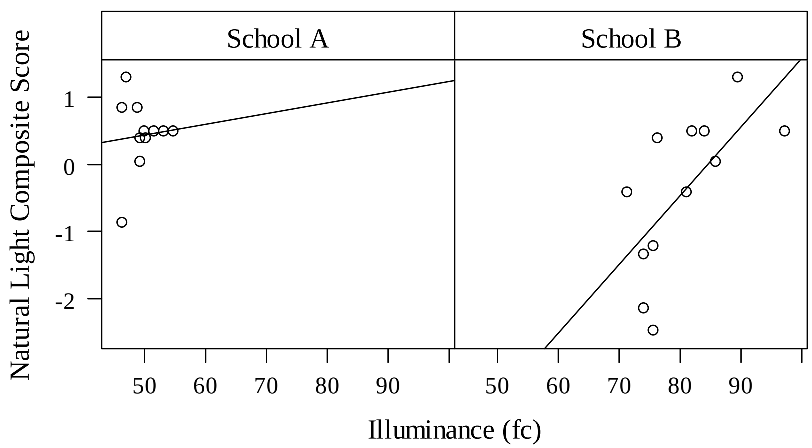
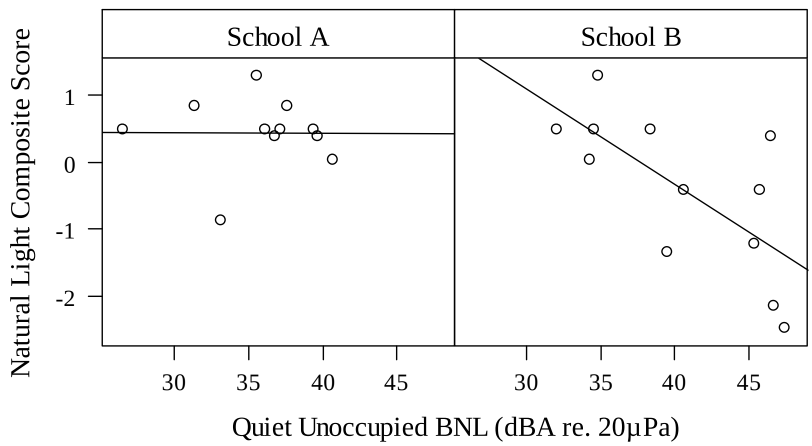


***Figure 4-31*: Natural Light Composite Score by Illuminance Within School**



Unoccupied quiet background noise, **`bnllow`**, predicts satisfaction with natural light, both with and without school as a regressor. However, the interaction term is a moderate predictor that makes background noise insignificant. *Figure 4-32* shows the effect of this interaction. This suggests that background noise has a different impact at School A than at School B. The evidence suggests higher background noise levels may lower teachers' satisfaction with natural light. In addition, when the composite **naturaltot** is regressed onto organizational satisfaction and **bnllow**, organizational satisfaction (*p* = 0.010) and background noise levels (*p* = 0.001) are both good predictors. As background noise levels decreased and organization satisfaction increased, natural light satisfaction increased.

***Figure 4-32*: Natural Light Composite Score by BNL Within School**



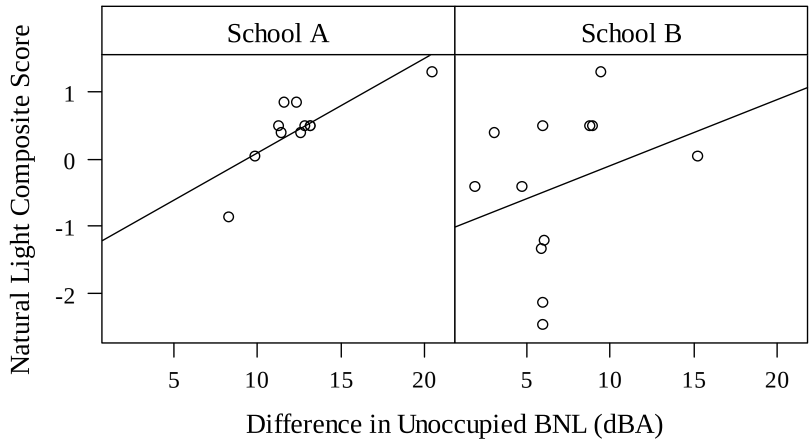
The effect of noise from the classroom mechanical system is conceptualized as the difference between unoccupied high and low sound pressure levels. The 4-minute average is used for this calculation, which is convenient in the **bnllow** and **bnlhigh** variables. The variable **bnldelta** is constructed from the background noise levels as follows.

bnldelta = (**bnlhigh – bnllow**)

When the natural light composite is regressed onto **bnldelta** and **school**, **bnldelta** is a moderate predictor (*p* = 0.057), as illustrated in *Figure 4-33*. In addition, when **naturaltot** is regressed onto **bnldelta**, **school** and **orgsat**, both **orgsat** (*p* =

0.058) and **bnldelta** (p = 0.064) are moderate predictors. All lighting tests are summarized in Table B-2 and Table B-3 of Appendix B.

***Figure 4-33*: Natural Light Composite Score by Background Noise Delta**



SECTION 4.9 - Furnishings Results

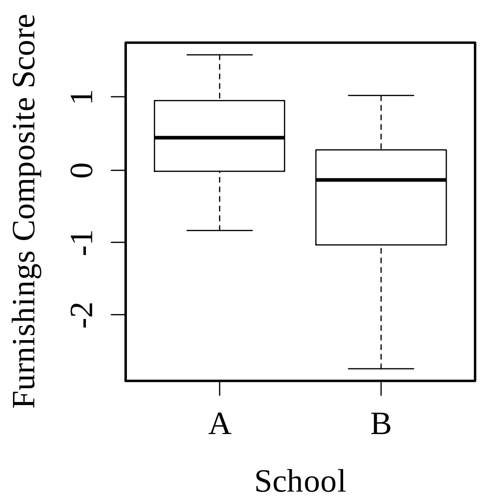
Furniture items are reliable with a Cronbach's alpha of 0.87. Based on high correlations, all items are included in the composite furniture score, **furntot**. As presented in Table 4-2, the furnishings composite is also significantly correlated with satisfaction in classroom size, views, acoustics and air quality. The broad IEQ composite score, **ieqT,** also is related to the furniture composite score.

Table 4-11: ***Pearson's Correlations of Furniture Outcome Items***

Survey Item Summary		Variable	1	2	3	4	5	6
How satisfied are you with the comfort of furniture for adults?	1	`furnadult`	-					
How satisfied are you with the comfort of furniture for children?	2	`furnchild`	0.46	-				
How satisfied are you with .. the adjustability of furniture?	3	`furnadjust`	0.64 ***	0.75 ***	-			
How satisfied are you with the furniture layout…?	4	`furnlayout`	0.57 **	0.52 **	0.74 ***	-		
How satisfied are you with the colors and textures …?	5	`finishes`	0.28	0.48 *	0.48 *	0.53 **	-	
Does the furniture interfere with your ability to do your job?	6	`furninterfere`	0.53 **	0.50 *	0.59 **	0.70 ***	0.57 **	-

Teachers at School A report significantly higher satisfaction with furnishings than those at School B, as illustrated in *Figure 4-34*.

***Figure 4-34*: Furnishings Composite Score by School**



Color was a significant predictor of satisfaction ($p = 0.011$). When the furnishings composite score was regressed onto wall color and school, color was a moderate predictor ($p = 0.077$), as plotted in *Figure 4-35*. Cool colors related to higher scores. In addition, when the furnishings composite score was regressed onto carbon dioxide levels and school, both variables were significant predictors. Higher carbon dioxide concentrations predicted lower furniture composite scores, as illustrated in *Figure 4-36*. A summary of these tests is provided in Table B-2 and Table B-3.

***Figure 4-35*: Furnishings Composite Score by Wall Color**

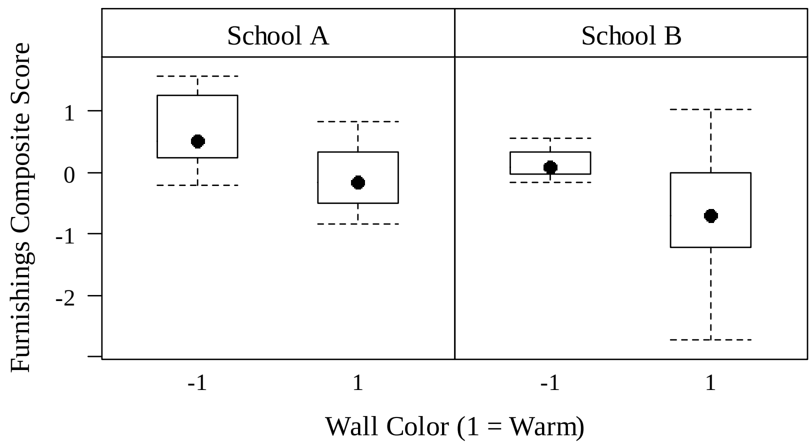
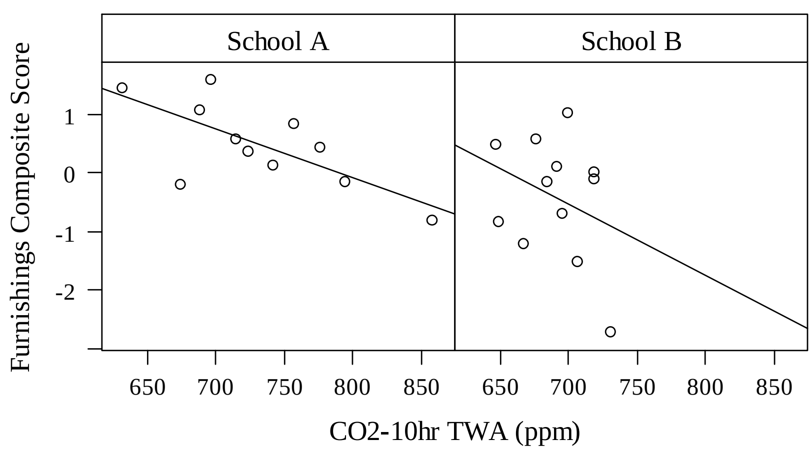


***Figure 4-36*: Furnishings Composite Score by Carbon Dioxide Concentration**



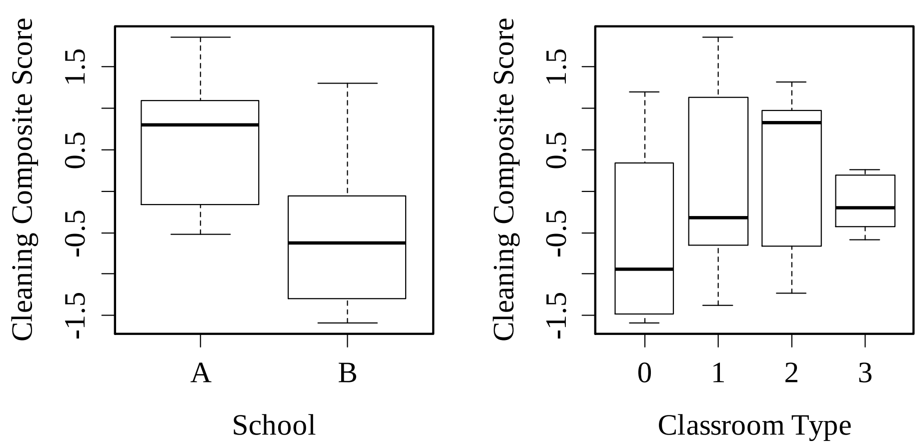
SECTION 4.10 - Cleaning Results

Items in the cleaning domain are reliable with a Cronbach's alpha of 0.85. The items were correlated as indicated Table 4-12. All items were included in the composite score, **`cleantot`**. Cleaning composite scores are significantly higher at School A than at School B. Classroom type does not predict satisfaction with cleaning. Scores are described in *Figure 4-37*.

Table 4-12: ***Pearson's Correlations of Cleaning Outcome Items***

Survey Item Summary		Variable	1	2	3	4	5
How satisfied are you with the tidiness of your classroom?	1	**`cleanorg`**	-				
How satisfied are you with the cleaning service in your classroom?	2	**`cleanservice`**	0.42 *	-			
How satisfied are you with the wall display surfaces?	3	**`cleandisplay`**	0.64 **	0.58 **	-		
Which of the following are problems…? [inverted scale]	4	**`cleanprob`**	0.38	0.54 **	0.62 **	-	
Does the cleaning and organization interfere with your ability to do your job?	5	**`cleaninterfere`**	0.53 **	0.52 *	0.53 **	0.58 **	-

***Figure 4-37*: Composite Cleaning Score by School and Classroom Type**



When the cleaning composite score, **`cleantot`**, is regressed onto school and wall color, color predicted satisfaction (p = 0.021), as illustrated in *Figure 4-38*. When the composite is regressed onto school and illuminance levels, both predictors are significant. Higher classroom illuminance values are associated with higher scores as shown in *Figure 4-39*.

***Figure 4-38*: Cleaning Composite Score by Wall Color**

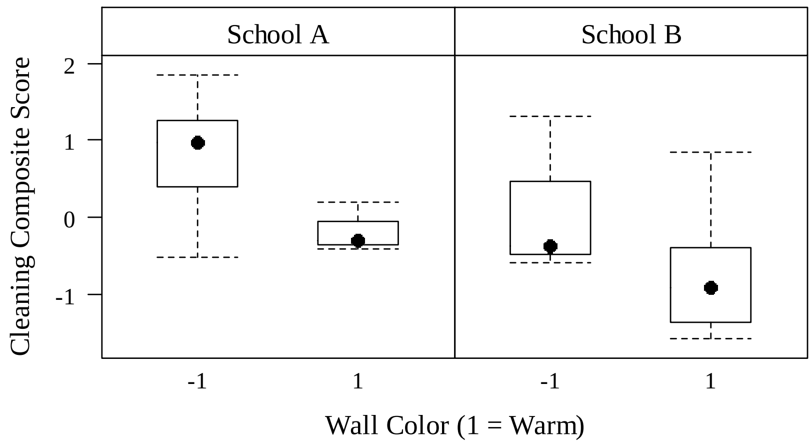
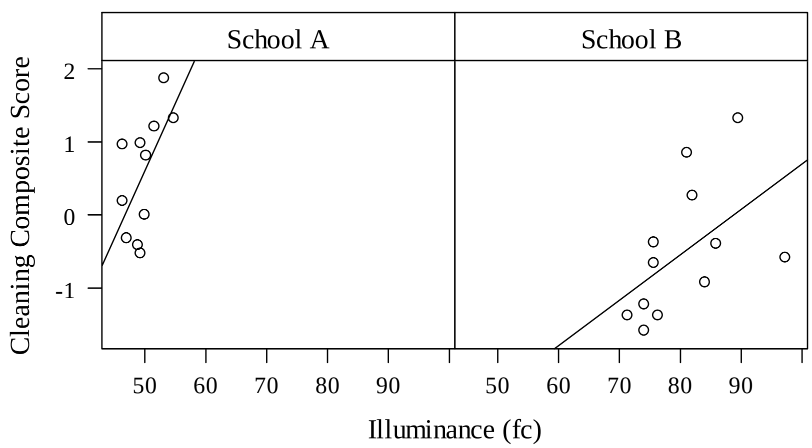


***Figure 4-39*: Cleaning Composite Score by Illuminance**



Area is also a predictor, but the effect is not significant when the interaction with school is included as a regressor. When the cleaning composite score, **`cleantot`**, is regressed onto area, school and interaction **`area`**X**`school`**, school (p = 0.009) and the interaction term (p = 0.019) are significant, but area is not (p = 0.109). Reverberation time is a predictor, although this is hypothesized to be confounded with room area.

Figure 4-40 illustrates the composite cleaning score regressed onto reverberation time (p = 0.045) and school (p = 0.002), where both predictors were significant. When `cleantot` was regressed onto the 10-hour carbon dioxide concentration and school, carbon dioxide (p = 0.058) was a moderate predictor, and school was a good predictor (p = 0.001). This test is illustrated in *Figure 4-41*. A similar result was obtained for the 15-minute carbon dioxide concentration. These models are summarized in Table B-2 and Table B-3.

***Figure 4-40*: Cleaning Composite Score by Reverberation Time**

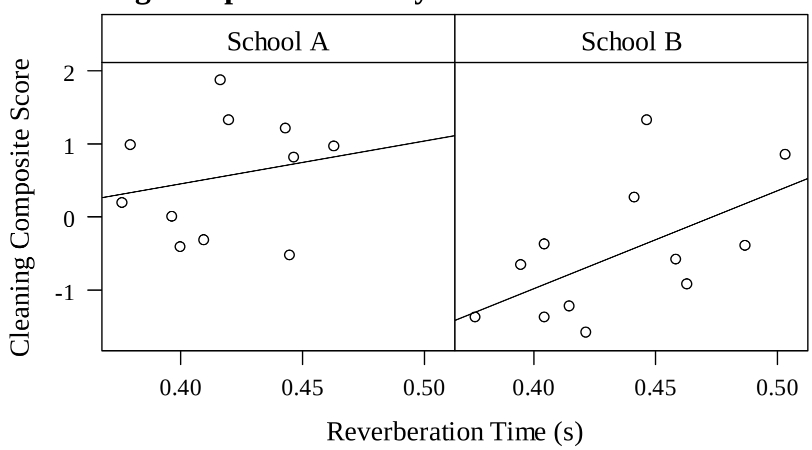
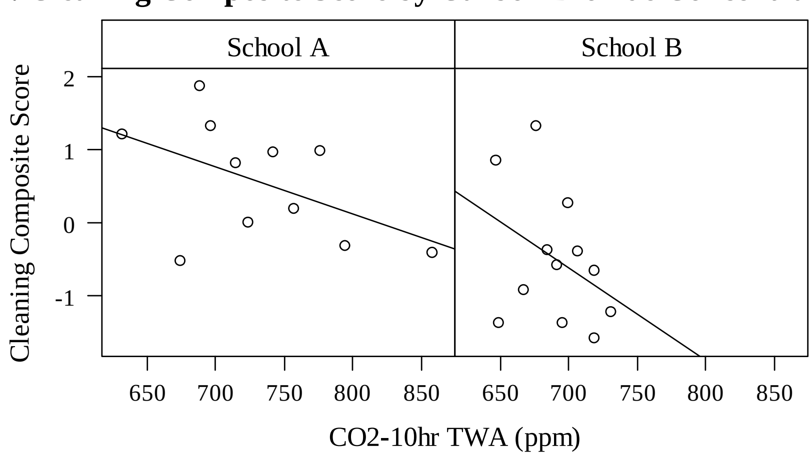


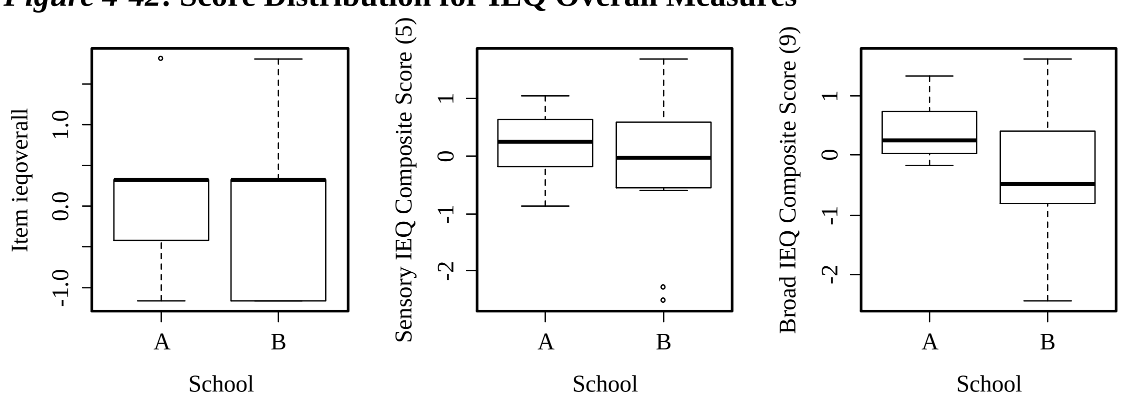
***Figure 4-41*: Cleaning Composite Score by Carbon Dioxide Concentration**



SECTION 4.11 - Global IEQ Results

4.11.1- Survey results. This study uses three scores to represent global IEQ satisfaction. The most basic is from the last item on the survey, **`ieqoverall`**, which reads, "All things considered, how satisfied are you with your classroom?" The semantic differential scale for this item is coded 1 through 6, and all participants responded at the levels of 4, 5, or 6, as listed in Table B-1. The other two global IEQ scores are composites created from the domain composite scores that are described in the sections above. A broad global score, **`ieqT`**, combined all the domain composites by first converting them to z scores, thereby providing equal weight to each. Therefore, this broad global score combined nine domain composites, or 30 survey items, listed in Table 4-1. The third measure of global IEQ quality targeted the sensory environment, **`ieq.sensory`**. This score was created from the five domain composites: **`accsat2`**, **`thermsat`**, **`airtot`**, **`lighttot`** and **`naturaltot`**. Therefore, **`ieq.sensory`** represents 14 survey items. Score distributions are presented in *Figure 4-42*.

***Figure 4-42*: Score Distribution for IEQ Overall Measures**



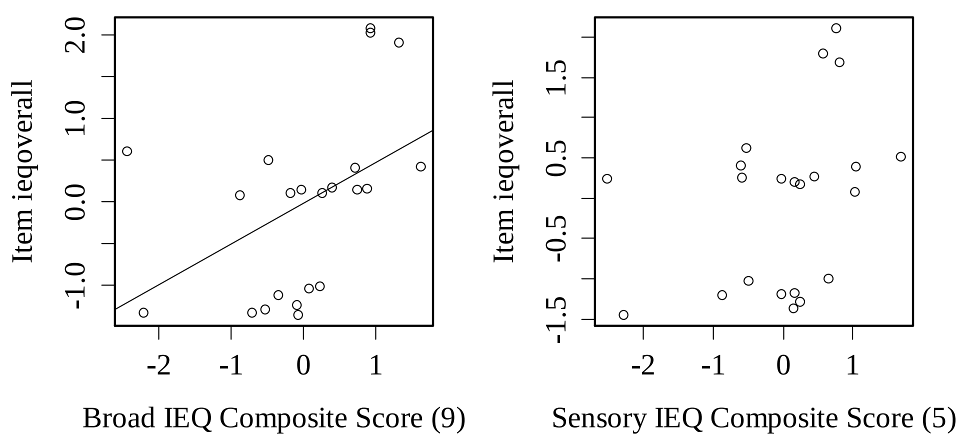
None of the global IEQ scores differed significantly between schools, although the broad IEQ composite, **`ieqT`,** was most different ($p = 0.066$). The score distributions are shown in *Figure 4-42*. The overall IEQ item is significantly correlated with **`ieqT`** (r =

0.48) but not with **ieq.sensory** (*r* = 0.32). When the item **ieqoverall** was regressed onto **ieqT** and **school**, **ieqT** was still a significant predictor (*p* = 0.024). This suggests that when answering about overall classroom satisfaction, teachers include considerations beyond just the acoustic, lighting, thermal and respiratory conditions. Because the two composite global IEQ scores share five domain composites, they are significantly related to each other (*r* = 0.89). Table 4-13 lists the correlations between the three IEQ survey scores, and *Figure 4-43* illustrates the relationship between the item **ieqoverall** and both IEQ composite scores.

Table 4-13: ***Pearson's Correlation of IEQ Scores***

IEQ Item		Variable	1	2	3
All things considered, how satisfied are you with your classroom?	1	**ieqoverall**	-		
Composite of **accsat2**, **thermsat**, **airtot**, **lighttot**, and **naturaltot**	2	**ieq.sensory**	0.32	-	
Composite of **sizesat**, **viewsat**, **accsat2**, **thermsat**, **airtot**, **lighttot**, **naturaltot**, **furntot**, **cleantot**	3	**ieqT**	0.48 *	0.89 ***	-

***Figure 4-43*: Item ieqoverall by IEQ Composite Scores**

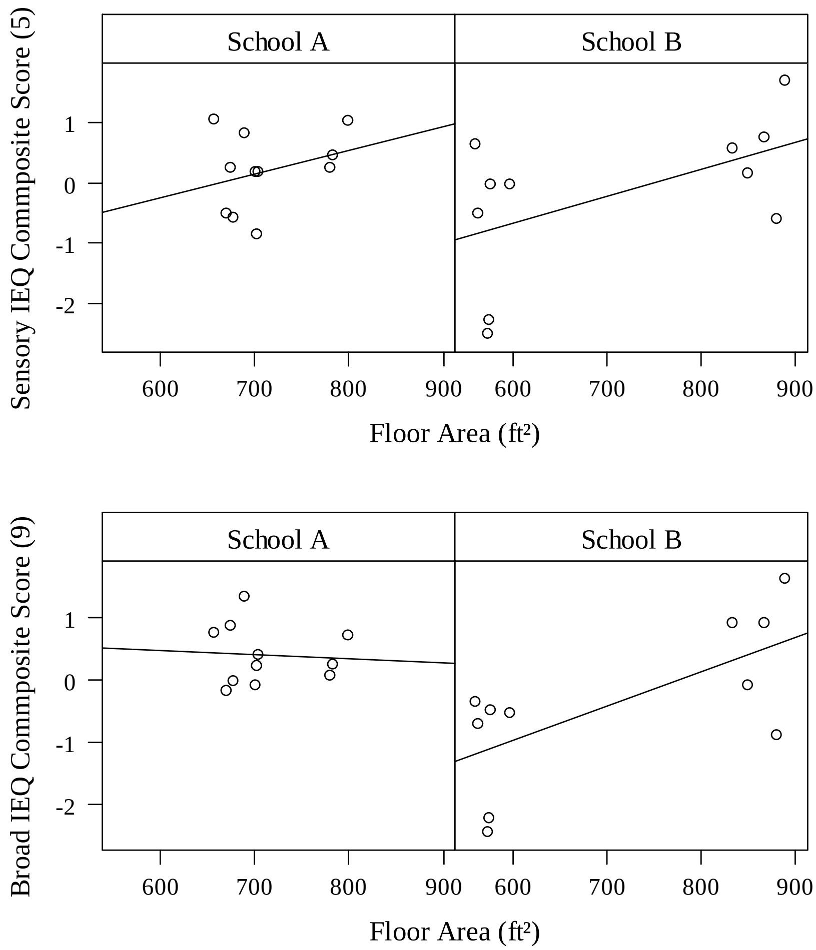


Each of the three global IEQ scores were tested for relationships with teacher characteristics including age, experience, length of assignment to classroom, title and organizational satisfaction. When the IEQ overall item was regressed onto organizational satisfaction composite score and school, **`orgsat`** was a moderate predictor (p = 0.086). This test is listed in Table B-3. Other teacher characteristics were not correlated with the scores.

4.11.2- Findings. Of the three global IEQ scores, the broad composite **`ieqT`** was related most to measurements in the physical environment, while the single item **`ieqoverall`** showed the fewest relationships. For tests with **`ieqoverall`**, **`orgsat`** was included in the compact model and **`school`** was not. This is because **`orgsat`** was a good predictor of **`ieqoverall`**, while scores did not vary significantly between schools as discussed above. When the item **`ieqoverall`** is regressed onto **`orgsat`** and **`plants`**, both **`orgsat`** (p = 0.023) and **`plants`** (p = 0.049) are significant predictors. Similarly, when **`ieqoverall`** is regressed onto **`carpet`** and **`orgsat`**, **`carpet`** is a moderate predictor (p = 0.076), and **`orgsat`** is a significant predictor (p = 0.050). There was also a relationship between thermal comfort and the **`ieqoverall`** item. When **`ieqoverall`** was regressed onto **`orgsat`** and relative humidity, relative humidity was a significant predictor (p = 0.043). These tests are summarized in Table B-2 and Table B-3.

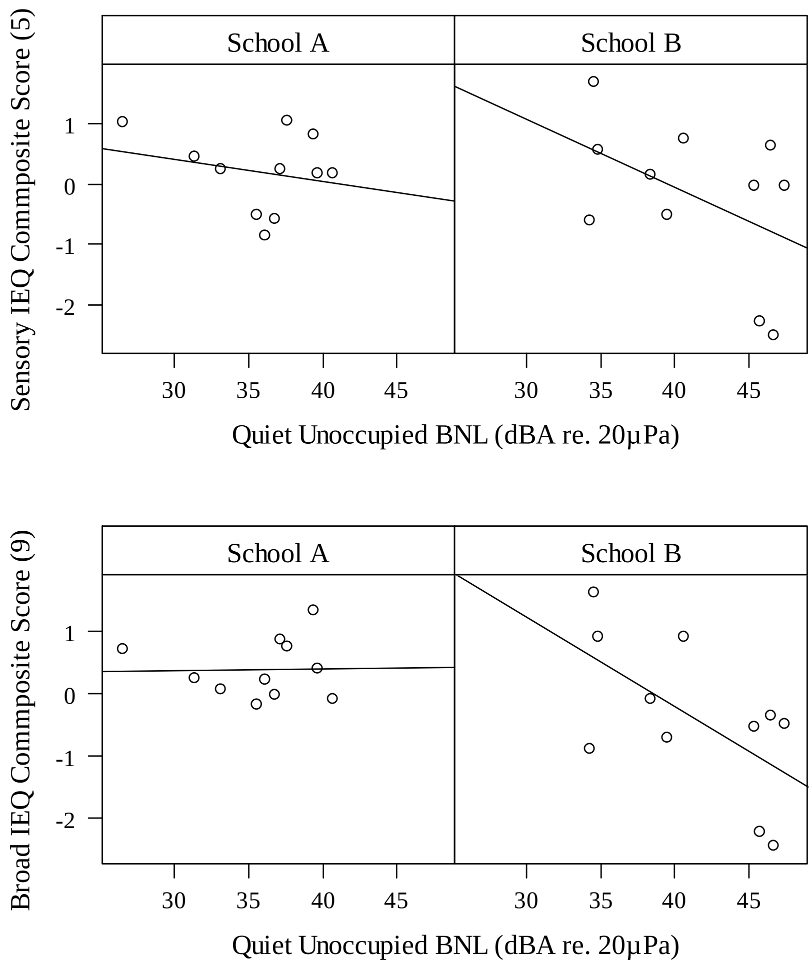
Findings for the two composite IEQ scores **`ieqT`** and **`ieq.sensory`** are discussed together. When the sensory IEQ composite, **`ieq.sensory,`** was regressed onto **`area`** and **`school`**, **`area`** was a significant predictor (p = 0.021). When the broad IEQ composite, **`ieqT,`** was regressed onto **`area`** and **`school`**, both **`area`** (p = 0.005) and **`school`** (p = 0.036) were significant predictors. When the interaction term was included in the model for **`ieqT`**, it was not significant. The bimodal nature of floor area at School B and the corresponding difference in teacher satisfaction helps describe this result, since both scores and area within School A do not vary as widely. This is illustrated in *Figure 4-44*.

***Figure 4-44*: Area by IEQ Scores Within School**



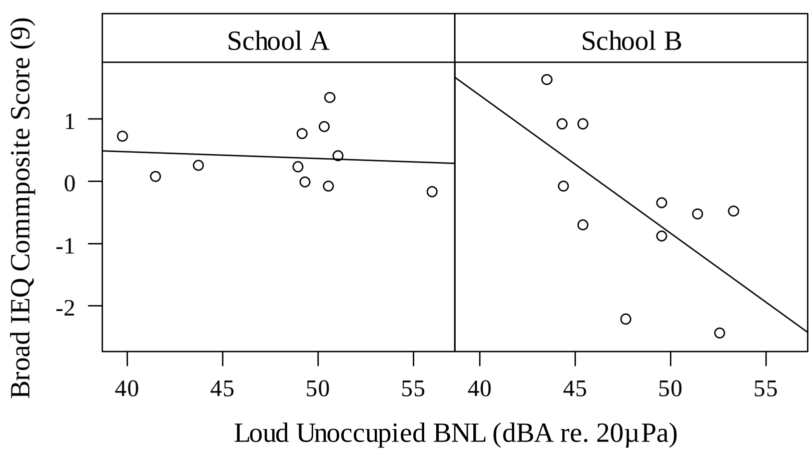
There were several relationships between acoustics and composite IEQ scores. When the sensory IEQ composite, **`ieq.sensory,`** was regressed onto quiet unoccupied background noise levels (**`bnllow)`** and school, **`bnllow`** was a moderate predictor (p = 0.074). While this relationship is present at School A, a group of low scores at school B in rooms with high unoccupied, A-weighted background noise levels around 45 dB re 20 µPa makes the effect more pronounced, as illustrated in *Figure 4-45*. There is a similar relationship to the broad IEQ composite. When the composite **`ieqT`** was regressed onto quiet unoccupied background noise levels and school, **`bnllow`** was a significant predictor ($p = 0.046$). When **`ieqT`** was regressed onto quiet unoccupied background noise levels and school, including the interaction **`bnllow`**X**`school`**, only the interaction term was a moderate predictor ($p = 0.083$). This suggests stronger differences between schools in the effect of background noise levels on teacher satisfaction. That the average A-weighted **`bnllow`** of School B is a significant 4.6 dB higher than that of School A is a consideration in interpreting this result.

***Figure 4-45*: Unoccupied Quiet BNL by IEQ Scores Within School**



The relationships between teacher IEQ satisfaction and quiet unoccupied background noise level (**`bnllow`**) are similar to those of loud background noise level (**`bnlhigh`**). The average A-weighted **`bnlhigh`** measurement at School A is about 1 dB higher than at school B, an insignificant difference as noted in Table A-3. When the sensory IEQ composite score, **`ieq.sensory,`** is regressed onto **`bnlhigh`** and **`school`**, **`bnlhigh`** is a moderate predictor (p = 0.057). The interaction of **`bnlhigh`**X**`school`** is not significant when added to the model. When the broad IEQ composite score, **`ieqT,`** is regressed onto **`bnlhigh`** and **`school`**, **`bnlhigh`** is a moderate predictor (p = 0.084), and **`school`** is a significant predictor (p = 0.046). However, when **`ieqT`** is regressed onto **`bnlhigh`**, **`school`** and the interaction **`bnlhigh`**X**`school`**, only **`school`** and the interaction term are significant. This suggests that the background noise of mechanical systems has a bigger negative impact on teacher IEQ satisfaction at School B than at School A. This is illustrated in *Figure 4-46*.

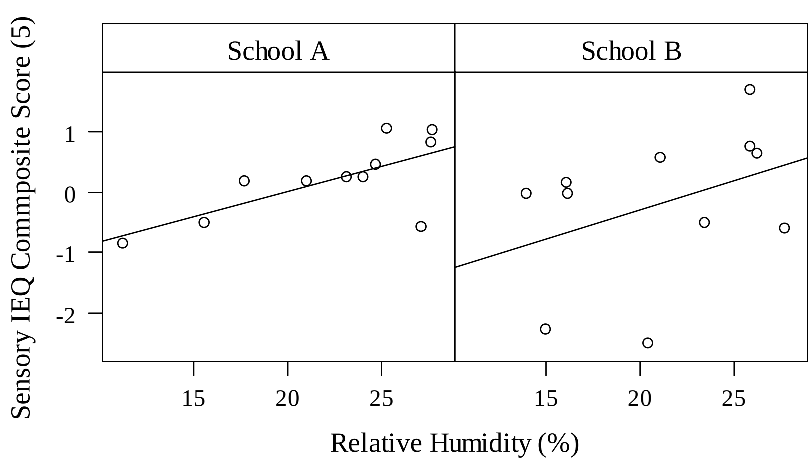
***Figure 4-46*: Unoccupied Loud BNL by Broad IEQ Score Within School**



Reverberation time is related to IEQ satisfaction, although this finding may be due to the confound of area with reverberation time. When the broad IEQ composite score, **ieqT,** was regressed onto reverberation time and school, both **rt20** (*p* = 0.030) and **school** (*p* = 0.018) were significant predictors. Higher reverberation times were associated with higher scores. When the sensory IEQ composite score, **ieq.sensory,** was regressed onto reverberation time and school, both **rt20** was a moderate predictor (*p* = 0.089).

There was no effect of particulate matter concentrations on IEQ composite scores. The suspended dust in classrooms varied most by classroom type. When the effect of classroom type was included in the regression, there was still no effect on teacher scores. Relative humidity predicted the sensory IEQ composite score and was a moderate predictor of the broad IEQ composite score. When **ieq.sensory** was regressed onto **rh10** and **school**, **rh10** was significant with *p* = 0.033 as illustrated in *Figure 4-47*. When **ieqT** was regressed onto **rh10** and **school**, both **rh10** (*p* = 0.090) and **school** (*p* = 0.085) were moderate predictors. These tests are provided in Table B-3. This suggests that the sensory IEQ composite score may be less sensitive to differences between schools than the broad IEQ composite score.

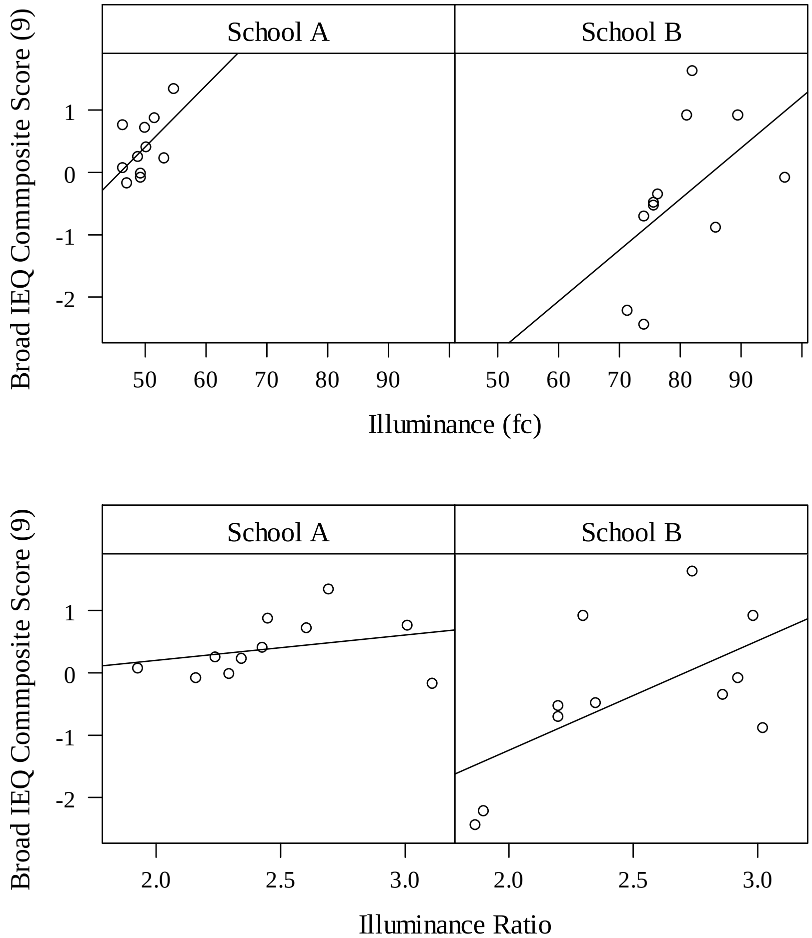
***Figure 4-47*: Composite Sensory IEQ Score by Relative Humidity**



The average high electric lighting levels in a classroom correlate with teacher satisfaction, with more illuminance matched with higher scores. The two schools were significantly different in illuminance levels, with School B measuring on average 30.9 footcandles more than School A, as described in Appendix A, Table A-4. When the sensory IEQ composite, **`ieq.sensory`**, was regressed onto illuminance levels and school, **`illum`** (p = 0.099) and **`school`** (p = 0.064) were both moderate predictors. When the broad IEQ composite, **`ieqT`**, was regressed onto illuminance levels and school, **`illum`** (p = 0.015) and **`school`** (p = 0.004) were both significant predictors. These tests are listed in Table B-3 and illustrated in *Figure 4-48*. The broad IEQ score was more related to classroom illuminance levels than was the sensory IEQ score, suggesting that items related to satisfaction with area, size, cleaning and furnishings are impacted by lighting levels.

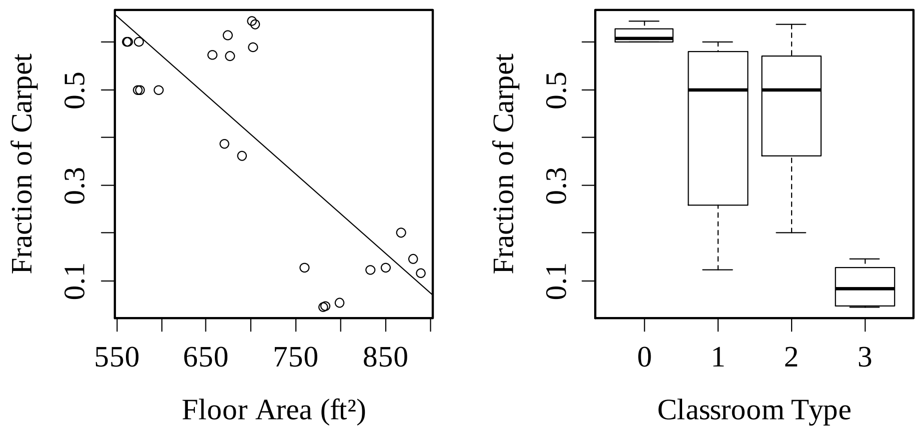
Higher illuminance ratios in classrooms related to higher teacher IEQ scores for both IEQ composites. When the sensory IEQ composite, **`ieq.sensory`**, was regressed onto illuminance ratio and school, **`illumratio`** was a significant predictor (p = 0.014). When the broad IEQ composite, **`ieqT`**, was regressed onto illuminance ratio and school, **`illumratio`** (p = 0.018) and **`school`** (p = 0.038) were both significant predictors. These tests are listed in Table B-3 and illustrated in *Figure 4-48*.

***Figure 4-48*: Illuminance and Illuminance Ratio by IEQ Scores Within School**



Color is a moderate predictor of **ieqT** but not when school is included as a regressor. When **ieqT** is regressed onto color and classroom type, **color** is a significant predictor (p = 0.032). The number of hiding spaces in a classroom was negatively correlated with **ieqT**, although this was not significant with school included in model. The fraction of permanent carpet in rooms predicts the sensory IEQ composite score with school included as a regressor. For the broad IEQ composite, carpet is a moderate predictor. In both cases, a greater fraction of permanent carpet corresponded with lower IEQ satisfaction scores. These findings, listed in Table B-3, may be the result of another variable confounded with carpet type, such as room area or classroom type. These confounds are illustrated in *Figure 4-49*.

***Figure 4-49*: Confounds with Carpet**



SECTION 4.12 - Summary

The teacher survey generated the outcome measure for this study with items combined to form composite scores for each domain. These composites also were combined and further analyzed as a measure of global IEQ. All of the statistical tests are listed in Table B-2 of Appendix B. Table B-3 also includes the output of statistical analysis from the R software employed. A summary of the findings that represent strong patterns in the data is provided in Table 4-14, organized by domain composite score. As a measure of the internal structure of the survey, each composite score also is compared to the item **`ieqoverall`** in this table using Spearman's rho. Results reinforce the correlations calculated in Table 4-2, with view, size and cleaning composite scores strongly related to the item **`ieqoverall`**.

Table 4-14: ***Composite Score Summary***

Composite Score	Notable Predictive Tests [significance: *p* < *0.10* & ***p* < 0.05**]	Spearman's rho (ρ) to ieqoverall (*p* value)
sizesat	**area + school, bnllow + school, bnllow** + *crtype* + *school*X*crtype*	**0.517** (*0.011*)
viewsat	**illumratio** + school	**0.531** (*0.009*)
accsat2	**area + school, bnllow +** school**,** *bnlhigh* **+ school, rh10 +** *school*	0.238 (*0.274*)
thermsat	*color* **+ crtype, orient.factor** + **crtype**	0.057 (*0.795*)
airtot	*co210* + school, *co215* + school, *onoff10* + school	0.157 (*0.486*)
lighttot	**illumratio** + school	0.219 (*0.316*)
naturaltot	**illum** + school, **bnllow** + school, bnllow + school **+** *bnllow*X*school*, **bnllow +** school **+ orgsat, bnldelta +** *orgsat*	0.364 (*0.088*)
furntot	*color* + school**, co210 + school, co215 + school**	0.252 (*0.247*)
cleantot	area **+ school + area**X**school, color** + school**,** *co210* **+ school,** *co215* **+ school**	**0.492** (*0.017*)
ieq.sensory	**area** + school**, carpet** + school, *bnllow* + school, *bnlhigh* + school, *illum* **+** *school*, **illumratio** + school, **rh10** + school	0.397 (*0.067*)
ieqT	**area + school, carpet + school, bnllow +** school, *rh10* + school bnlhigh + **school + bnlhigh**X**school illum + school, illumratio + school, color** + crtype	**0.576** (*0.005*)
ieqoverall	*orgsat*, **plants + orgsat**	1.000 (N/A)

CHAPTER 5 - Discussion

As with other places of employment, the physical environment of early learning schools impacts the behavior of occupants. Following the framework presented in Chapter 1, this study contributes to the literature on early education and IEQ in several ways. As detailed in Chapter 4, findings show the physical environment does predict teacher satisfaction scores with IEQ on a self-reported assessment. Further, the study suggests that organizational satisfaction may mediate satisfaction with IEQ. A third contribution of this study is insight into the reliability and validity of the survey tool developed for this study in assessing IEQ, as currently understood in the literature.

SECTION 5.1 - Physical Environment and IEQ Satisfaction

The study strongly suggests that the physical environment predicts teacher satisfaction with IEQ. The picture that emerges from the findings shows complex relationships between overall satisfaction and satisfaction with various sensory domains. Additionally, measurements from one domain in the physical environment often predicted IEQ satisfaction in a different domain. This finding supports Humphrey's (2005) observations regarding the complexities of forming a unitary IEQ index that would be applicable for various populations and different building users.

SECTION 5.2 - Organizational Satisfaction and IEQ Satisfaction

Structural and symbolic variables are intertwined (Cheryan et al., 2014). This study suggests that classroom features such as color can be as important to occupant satisfaction as the temperature. In addition, the general composite score, which aggregates satisfaction with furnishing and finishes, is predicted by several domains in the physical environment, suggesting that the lighting and background noise can influence perception of the general accommodations in a classroom. Similarly, the broad IEQ composite score was predicted by more measurements in the physical environment than was the targeted sensory IEQ composite score.

SECTION 5.3 - Survey Structure and Discussion

Preliminary analysis with all 44 participants suggested that teachers' satisfaction scores were dependent on teacher characteristics, such as organizational satisfaction, age and length of time teachers had been assigned to the same room. While these teacher-level characteristics were moderately predictive of some items in the final analysis with 23 teachers, the relationships were not as suggestive or broad in effect on satisfaction items. The sample selected of 18 Lead Teachers and 5 Assistant Teachers intentionally excluded teachers with lower titles who also generally reported lower scores. In addition to the loss of power, this loss of variance in scores may be one reason teacher characteristics were less suggestive of scores in the final analysis.

Teachers with less organizational status may respond differently to interventions in the physical environment than teachers in more established positions. For example, Teacher's Aides may be more satisfied if their classroom assignments change more frequently than would teachers with more tenure. The correspondence between organizational satisfaction and IEQ satisfaction also suggests that interventions in the physical environment may improve employee engagement for teachers with less status.

Grouping behavioral items into composite scores is an important feature of this study. Correlations between teacher responses and the physical environment tended to remain when the items were grouped with other items. For example, illuminance was a strong predictor for the **naturalsat** item on the survey, which is aggregated into **naturaltot** that also correlated to illuminance. This composite is grouped further into the broad composite IEQ score, **ieqT**, which is also predicted by illuminance. In contrast, no emergent relationships are obvious because of aggregating items. Therefore, the composite score did not appear to create a more accurate measure of occupant behavior as predicted by the physical environment.

An important feature of the study methodology is that items were excluded to improve the predictive power of the physical environment. In addition, five of the composite scores included an item that was worded to reflect occupant performance as opposed to occupant satisfaction. For example, the item **airinterfere** was worded "Does the air quality interfere with your ability to do your job?" while the more typical item **airsat** was worded "How satisfied are you with the air quality in your classroom?" In the case of air quality, these items appeared to be measuring different yet meaningful psychological constructs based on the predictive power of the physical environment. The fact that selection based on Cronbach's alpha eliminated three of the eight "performance" items is further evidence that item wording is an important consideration is structuring IEQ satisfaction items.

When analyzing the agreement of different teachers in the same classroom, another issue arises concerning the definition of reliability. Reliability can be defined in the sense of inter-rater reliability, where the focus of analysis is how well different teachers agree in assessing the same classroom environment. Alternatively, a focus on intra-rater agreement considers how well a specific teacher observes differences in a classroom environment based on individual characteristics. While subtle, this distinction is analogous to the discussion of the dual purposes occupant surveys serve in the literature. Surveys can view occupants as a diagnostic instrument for fine-tuning building systems or, alternatively, target human behavior, with the physical environment conceptualized as a mediator of behavior. Regarding data analysis for the present study, the decision to select teachers to represent classrooms, instead of averaging teacher scores, is based on the latter approach of organizing the analysis around occupants, as opposed to environmental control systems.

SECTION 5.4 - IEQ Weightings

Heinzerling et al. (2013) reviewed the literature for various weighting schemes of occupant satisfaction with sensory domains. They formed weightings by creating a model that links items within a survey assessment to each other by using multivariate regressions, with overall satisfaction as the outcome measure. For comparison to their findings, a similar model is presented in Table 5-1 that regressed the **`ieqoverall`** item onto the sensory domain composite scores of **`accsat2`**, **`airtot`**, **`lighttot`**, **`naturaltot`** and **`thermsat`**. The column for lighting includes both composite scores for electric light and natural light used for this study. In contrast to the Heinzerling et al. study, results show that lighting was more predictive than acoustics of the overall IEQ item on the survey. Acoustics and air quality had approximately equal weight. Satisfaction with thermal comfort was correlated negatively to overall satisfaction in the multivariate model.

Table 5-1: ***Coefficient Comparison for IEQ Overall***

	Acoustics	IAQ	Lighting	Thermal Comfort
Heinzerling et al. (2013)	0.39	0.20	0.29	0.12
Current Study	0.09	0.09	0.20, 0.20	-0.06

SECTION 5.5 - Study Limitations

The study is a quasi-experiment that does not use random assignment. Samples are based instead on convenient groupings of participants, which demonstrated strong non-independence. This violates a fundamental assumption of many statistical tests used for data analysis – namely, that samples are randomly selected from a population and are independent.

The study has a small sample size and employs many variables in statistical tests, and therefore, some of the findings are very likely due to chance. There are 38 outcome items on the survey for IEQ, and many of these were tested for correlation to the physical environment individually. At the 0.05 significance level used for the study, at least one of these tests would result in a Type I error. When adding to this consideration the number of variables in the physical environment used in the study, the likelihood of false positive findings is strong. For this reason, findings are suggestive at best and can be interpreted as guidance for future research.

SECTION 5.6 - Implications for Building Users

In this study, many of the classrooms were scored by 2 or 3 teachers. The consistency of different raters is sometimes evaluated with a Fleiss Kappa test that returns 1 for total agreement and 0 for no agreement. When treated as raters of an objective domain, teacher performance was marginal with Fleiss Kappa of around 0.40. Using surveys as efficient ways to measure the environment has a proven record of accomplishment, although it is clear that such readings have significant “noise” from individual and group differences.

One of the questions this study asks is whether the survey tools can be conceptualized instead in the tradition of response-to-intervention, where they are viewed as one feature of a larger program that seeks to create optimal outcomes at the individual level. With the maturity of wirelesses sensor networks for commercial market, the concept of individualized comfort settings in open spaces is within reach. Anecdotally, one of the most sensitive sensory domains, acoustics, is treated commonly with earphones that selectively and wirelessly create soundscapes for occupants.

Researchers can conceptualize occupant surveys as a target construct in themselves, as opposed to indicators of the physical environment. While safe limits for the physical environment are a basic responsibility of designers, precisely describing target tolerances for each sensory domain may be less important to occupants than understanding the impact of change across sensory domains. For example, models of IEQ quality could conceptualize the rate of change in sensory domains as opposed to target ranges for each domain. Higher quality IEQ environments may be imagined to respond faster or slower to occupants' behavior and expressed desires.

Study findings suggest that satisfaction with the physical environments cannot be reduced to measurable variables in the physical environment. Instead, the way teachers use their classrooms in a social context is the best way to appraise their satisfaction with their classrooms. The practical opportunity suggested is that building users and designers are as accountable to building occupants as they are to budgets. More tenuously, designers have reason to suspect that engaging users in discussions about how they would like to interact with their sensory environment could translate into increased program outcomes, be they productivity, learning, sales or satisfaction.

SECTION 5.7 - Implications for Designers

This study shows that engineers and architects can address teachers' satisfaction with IEQ through design. Specifically, occupant surveys present a key strategy for improving IEQ. As demonstrated by the survey developed for this study, the value of responses is strongly related to the selection and wording of survey items. In addition, items can be grouped meaningfully into composite scores and retain much of their predictive power for quality in the physical environment. While it may be impossible to create a useful score related to combinations of variables in the physical environment, the perception of IEQ appears to be more unitary, with composite scores better reflecting satisfaction in the sensory domains.

CHAPTER 6 - Summary

This project compared physical measurements from classrooms at two early learning schools to teachers' self-reported satisfaction with IEQ. Forty-four teachers participated from twenty-three different classrooms, with some teachers reporting on the same classroom. Physical measures included unoccupied and occupied sound pressure level, reverberation time, occupied carbon dioxide and particulate matter concentrations, occupied temperature and relative humidity, and illuminance levels at one position at the ceiling. Various characteristics of the rooms were included such as floor area, floor covering, wall colors and the ability to separate the room from adjacent spaces.

Teacher characteristics such as time assigned to the same room, organizational satisfaction and school assignment all mediate satisfaction with the classroom IEQ. Findings show that unoccupied background noise levels, illuminance levels and floor area in the classroom are good predictors of overall satisfaction. Other predictors include classroom orientation, the color of the walls and average carbon dioxide concentration. An overall satisfaction score that combined several sensory domain composite scores was related strongly to the single survey item "All things considered, how satisfied are you with your classroom?"

Satisfaction with classroom size was predicted by floor area and unoccupied sound pressure level. Satisfaction with views was predicted by illuminance ratio, and satisfaction with acoustics was predicted by unoccupied background noise levels, noise level of mechanical equipment and relative humidity. Thermal comfort was predicted by classroom orientation and wall color, while satisfaction with air quality was predicted by carbon dioxide concentrations. Satisfaction with the electric lighting was predicted by illuminance ratio. Satisfaction with natural lighting was predicted by average illuminance and several measurements from the acoustic domain. Satisfaction with furnishings was predicted by wall color and carbon dioxide concentration, while satisfaction with cleaning correlated to illuminance, wall color and carbon dioxide concentration.

The survey tool revealed strong correlations between satisfaction levels of different sensory domains, such as temperature and acoustics and lighting and air quality. Self-reported satisfaction with overall IEQ was related to a broad composite score that combined 30 other survey items, supporting construct validity of the tool. This broad composite score exhibited more significant relationships to measures of the physical environment than a targeted sensory IEQ composite score.

The study does not feature random assignment and uses convenient samples that demonstrated strong non-independence. The study has a relatively small sample size and employs many variables in statistical tests, and therefore, some of the findings are very likely due to chance. Nonetheless, findings are strongly suggestive that differences in the physical environment correspond to satisfaction with IEQ. This intuitive finding lends support to the theory that quality in the physical environment affects program outcomes. The study also confirms that organizational satisfaction mediates satisfaction with IEQ, suggesting that the reverse may also be true.

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APPENDIX A - Predictor Variable Data

Table A-1: ***Observational Measures***

classroom code	**area** (square feet)	**color** (-1 = cool)	**plants** (number)	**blindsopen** (ordinal)	**hiding** (number)	**carpet** (ratio)	**crtype** (ordinal)
A18	657	-1	1	1	1	0.57	1
A19	701	-1	0	-1	0	0.64	0
A28	670	1	0	1	1	0.39	1
A38	690	-1	2	-1	0	0.36	2
A46	677	-1	0	0	1	0.57	2
A55	704	-1	1	0	1	0.64	2
A64	674	-1	0	0	0	0.61	0
A66	702	-1	1	-1	1	0.59	1
A88	780	1	1	-1	0	0.04	3
A91	799	-1	2	0	0	0.05	3
A94	783	1	4	0	0	0.05	3
B12	576	1	2	-1	2	0.50	2
B17	574	1	1	1	2	0.50	2
B19	881	1	1	-1	1	0.15	3
B25	833	-1	0	1	1	0.12	1
B33	759	1	1	-1	0	0.13	1
B54	563	1	1	0	1	0.60	0
B64	889	1	1	0	1	0.11	3
B66	561	1	0	0	1	0.60	1
B81	575	1	0	-1	0	0.60	0
B89	850	-1	1	1	1	0.13	3
B93	597	-1	2	-1	2	0.50	1
B97	867	1	3	-1	0	0.20	2
μ_A	712	-0.45	1.09	-0.18	0.45	0.41	1.64
σ_A	50.5	0.93	1.22	0.75	0.52	0.25	1.12
μ_B	710	0.50	1.08	-0.25	1.00	0.35	1.58
σ_B	146	0.90	0.90	0.87	0.74	0.22	1.08
$\boldsymbol{\mu}$	711	0.04	1.09	-0.22	0.74	0.38	1.61
$\boldsymbol{\sigma}$	109	1.02	1.04	0.80	0.69	0.23	1.08
p $\mu_A \neq \mu_B$	0.965	0.021 *	0.987	0.843	0.056	0.506	0.909

Table A-2: ***Classroom Air Quality and Thermal Comfort Measures***

classroom code	**tstat** (categorical)	**pm2510** (μg/m³)	**pm1010** (μg/m³)	**pm2515** (μg/m³)	**pm1015** (μg/m³)	**temp10** (°F)	**rh10** (%)	**co210** (ppm)	**co215** (ppm)
A18	-1	2.83	12.67	12.78	48.02	74.12	25.29	742.1	878.9
A19	-1	3.01	14.50	5.92	37.70	74.92	17.71	674.7	840.1
A28	-1	3.00	16.12	9.05	62.82	74.50	15.59	794.4	1026.5
A38	-1	3.97	19.54	10.16	60.52	73.91	27.61	696.4	841.7
A46	-1	7.57	33.19	40.23	150.0	72.86	27.12	776.4	912.7
A55	-1	3.78	18.35	8.12	72.23	74.94	20.98	714.8	809.2
A64	-1	3.76	10.40	23.25	52.92	73.96	23.13	632.3	694.1
A66	-1	6.51	17.97	51.83	158.4	78.27	11.30	688.6	859.9
A88	-1	15.69	168.61	186.71	2254.7	76.07	24.03	757.6	906.8
A91	-1	10.58	45.11	31.47	119.0	73.70	27.67	724.1	972.6
A94	-1	12.05	88.87	74.76	658.0	73.30	24.65	858.5	1087.5
B12	0	4.25	13.13	20.66	57.12	74.94	13.99	719.0	834.8
B17	0	2.86	13.31	7.47	46.02	78.15	20.43	731.3	893.2
B19	1	10.90	24.63	16.96	69.11	73.37	27.69	706.3	830.4
B25	0	4.19	10.47	9.46	47.11	76.68	21.08	676.5	788.3
B33	1	3.41	8.99	7.05	28.10	73.33	22.00	667.6	773.7
B54	1	4.83	10.85	16.55	27.08	81.03	23.41	719.2	810.0
B64	1	1.28	8.94	2.70	25.54	72.43	25.85	699.5	847.9
B66	1	4.05	10.18	6.08	27.78	73.07	26.25	649.2	749.3
B81	1	2.67	13.31	8.44	42.07	70.66	15.05	695.9	794.0
B89	1	2.58	14.91	10.70	75.30	73.48	16.11	691.9	877.0
B93	0	2.89	13.10	7.18	70.59	73.53	16.19	684.8	793.2
B97	1	1.71	8.56	9.09	40.35	69.27	25.84	647.0	737.1
μ_A	-1.00	6.61	40.48	41.30	334.04	74.60	22.28	732.71	893.62
σ_A	0.00	4.38	48.18	52.89	661.10	1.50	5.36	62.73	107.64
μ_B	0.67	3.80	12.53	10.20	46.35	74.16	21.16	690.67	810.72
σ_B	0.49	2.47	4.35	5.22	18.08	3.20	4.84	27.00	47.86
μ	-0.13	5.15	25.90	25.07	183.94	74.37	21.69	710.8	850.4
σ	0.92	3.72	35.62	39.21	469.48	2.49	5.01	51.13	90.58
p $\mu_A \neq \mu_B$	0.000***	0.069	0.058	0.055	0.146	0.686	0.603	0.046*	0.025*

Table A-3: ***Classroom Acoustical Measures***

classroom code	**rt20** (seconds)	**bnllow** (dBA re 20µPa)	**bnlhigh** (dBA re 20µPa)	**bnldelta** (dBA)	**laeq10** (dBA re 20µPa)	**l1** (dBA re 20µPa)	**l99** (dBA re 20µPa)	**acccontrol** (categorical)
A18	0.46	37.63	49.23	11.60	61.97	72.42	42.05	1
A19	0.45	40.70	50.60	9.90	63.61	73.60	44.95	1
A28	0.41	35.57	56.04	20.47	64.29	74.26	42.35	1
A38	0.42	39.36	50.64	11.28	63.37	73.06	46.17	1
A46	0.38	36.78	49.39	12.61	66.51	74.27	46.25	1
A55	0.45	39.68	51.11	11.43	64.27	74.58	43.43	1
A64	0.44	37.14	50.37	13.22	60.14	70.91	43.76	1
A66	0.42	36.16	49.00	12.85	61.81	70.45	37.04	1
A88	0.38	33.21	41.50	8.29	68.62	76.61	39.08	1
A91	0.40	26.62	39.81	13.20	66.12	76.73	33.75	1
A94	0.40	31.40	43.80	12.40	65.64	75.55	40.34	1
B12	0.40	47.38	53.37	5.99	68.63	78.24	48.99	-1
B17	0.42	46.62	52.60	5.98	67.67	79.20	46.78	-1
B19	0.49	34.32	49.60	15.28	71.51	79.25	49.51	-1
B25	0.45	34.89	44.34	9.45	68.26	77.16	43.51	-1
B33	0.46	32.07	40.88	8.81	64.69	75.45	40.30	1
B54	0.42	39.49	45.44	5.95	66.25	75.94	42.10	-1
B64	0.44	34.54	43.53	8.99	68.81	78.43	43.15	-1
B66	0.41	46.48	49.59	3.12	67.66	78.36	46.97	-1
B81	0.38	45.68	47.68	2.00	64.07	74.51	45.34	-1
B89	0.46	38.42	44.44	6.02	70.31	79.97	43.71	-1
B93	0.41	45.39	51.49	6.10	65.49	75.14	48.06	-1
B97	0.50	40.64	45.44	4.80	65.38	75.87	46.38	-1
μ_A	0.42	35.84	48.32	12.48	64.21	73.86	41.74	1.00
σ_A	0.03	4.10	4.73	3.04	2.43	2.06	3.91	0.00
μ_B	0.44	40.49	47.37	6.87	67.39	77.29	45.40	-0.83
σ_B	0.04	5.66	3.96	3.46	2.28	1.85	2.87	0.58
μ	0.43	38.27	47.82	9.55	65.87	75.65	43.65	0.04
σ	0.03	5.42	4.27	4.29	2.81	2.59	3.81	1.02
p $\mu_A \neq \mu_B$	0.251	0.036*	0.606	0.001***	0.004**	0.000***	0.018*	0.000***

Table A-4: ***Classroom Lighting Measures***

classroom code	`switches` (number)	`orient` (categorical)	`glarecontrol` (ratio)	`lpd` (Watts / ft^2)	`illum` (footcandles)	`illumratio` (ratio)	`onoff10` (ratio)
A18	4	-1	0.80	1.03	46.55	3.01	0.35
A19	4	1	0.70	1.12	49.40	2.16	0.85
A28	2	1	0.50	0.96	47.20	3.11	0.33
A38	2	1	0.60	1.01	54.90	2.69	0.94
A46	2	-1	0.75	1.12	49.45	2.29	0.20
A55	4	-1	0.75	1.12	50.30	2.43	0.19
A64	2	-1	0.75	1.12	51.65	2.45	-0.28
A66	4	-1	0.75	1.20	53.30	2.35	0.39
A88	2	-1	0.75	0.97	46.55	1.93	0.35
A91	4	1	0.75	1.06	50.00	2.60	0.34
A94	2	-1	0.75	0.97	48.95	2.24	0.33
B12	1.5	1	0.75	2.35	75.80	2.35	0.51
B17	1.5	-1	1.00	2.21	74.20	1.87	0.30
B19	1.5	-1	0.85	2.28	85.90	3.02	0.51
B25	1.5	-1	0.85	2.42	89.70	2.30	0.41
B33	2	-1	0.85	2.47	84.20	2.78	0.32
B54	3.5	-1	1.00	2.49	74.20	2.20	0.59
B64	1.5	1	1.00	2.20	82.20	2.74	0.40
B66	3.5	1	0.75	2.46	76.40	2.86	0.52
B81	3.5	1	1.00	2.44	71.40	1.90	-0.12
B89	1.5	1	0.60	2.31	97.30	2.92	0.41
B93	1.5	1	0.80	2.21	75.80	2.20	0.30
B97	1.5	-1	1.00	2.32	81.20	2.98	0.54
μ_A	2.91	-0.27	0.71	1.06	49.84	2.48	0.36
σ_A	1.04	1.01	0.09	0.08	2.66	0.35	0.32
μ_B	2.04	0.00	0.87	2.35	80.69	2.51	0.39
σ_B	0.89	1.04	0.13	0.11	7.60	0.42	0.19
$\boldsymbol{\mu}$	2.46	-0.13	0.80	1.73	65.94	2.49	0.38
$\boldsymbol{\sigma}$	1.04	1.01	0.14	0.66	16.75	0.38	0.26
p $\mu_A \neq \mu_B$	0.044*	0.532	0.003**	0.000***	0.000***	0.844	0.800

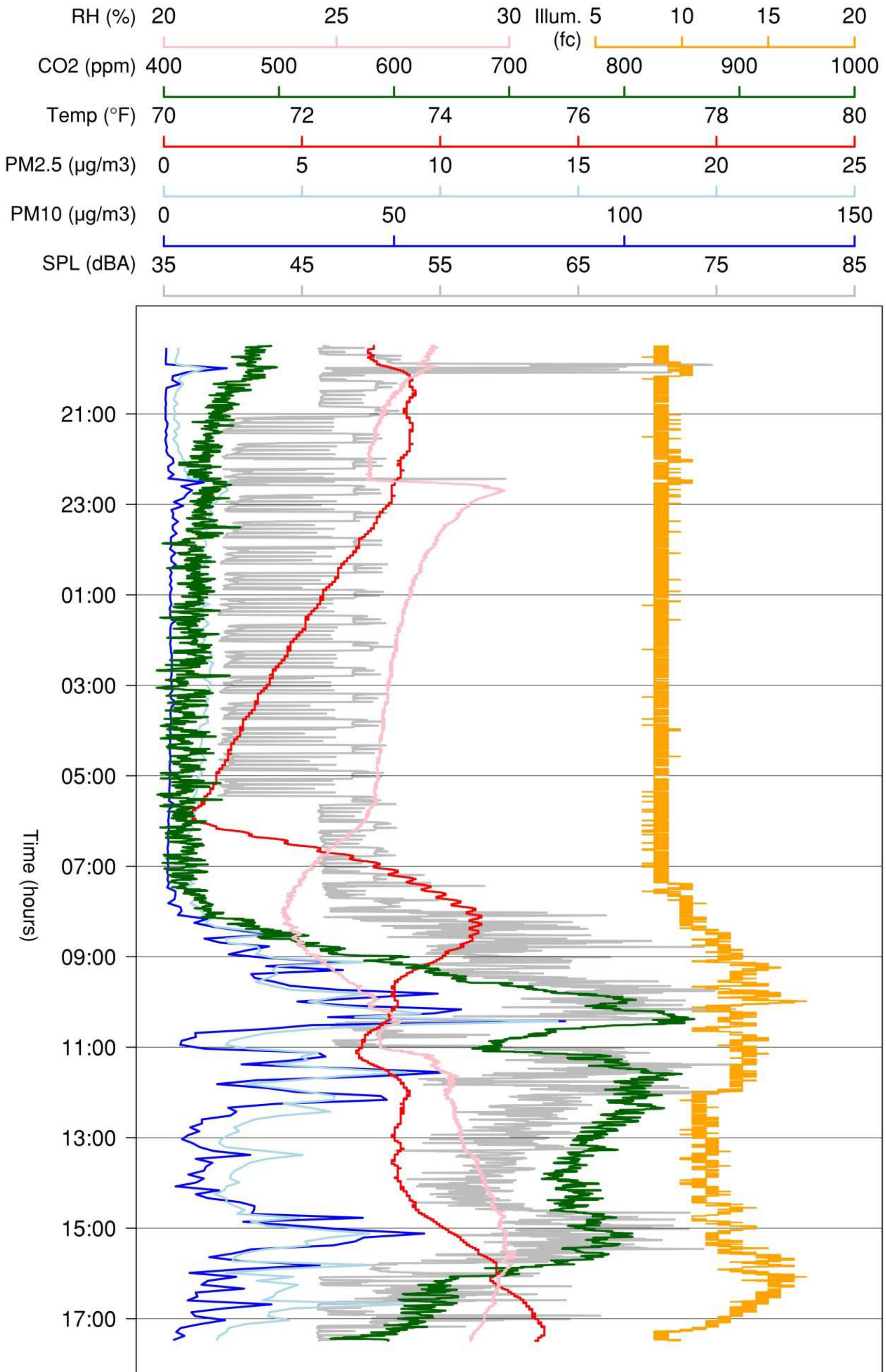

Figure A-1: **Room A38 Measures – 22 Hours**

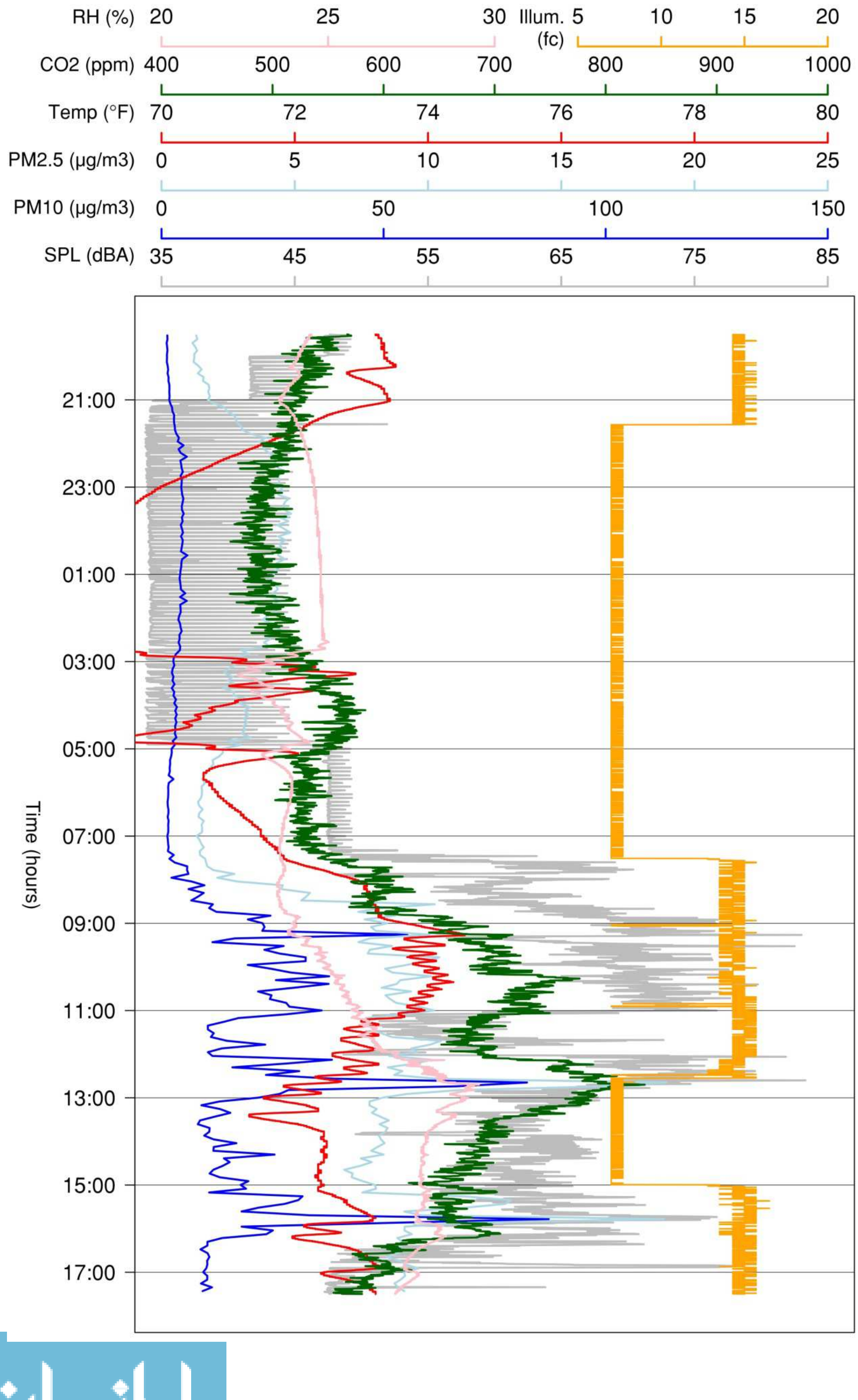

Figure A-2: **Room B24 Measures – 22 Hours**

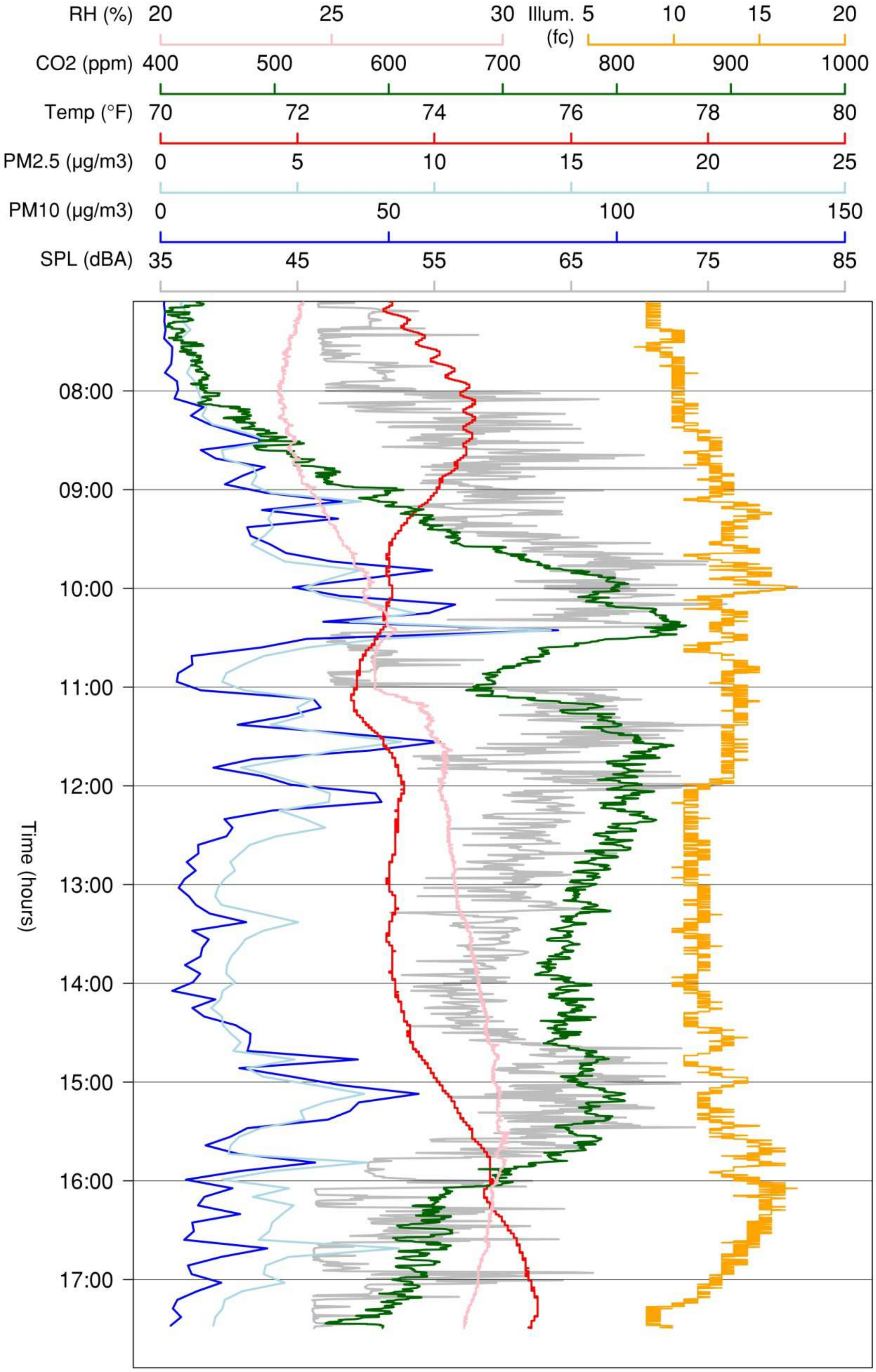

Figure A-3: **Room A38 Measures – 10 Hours**

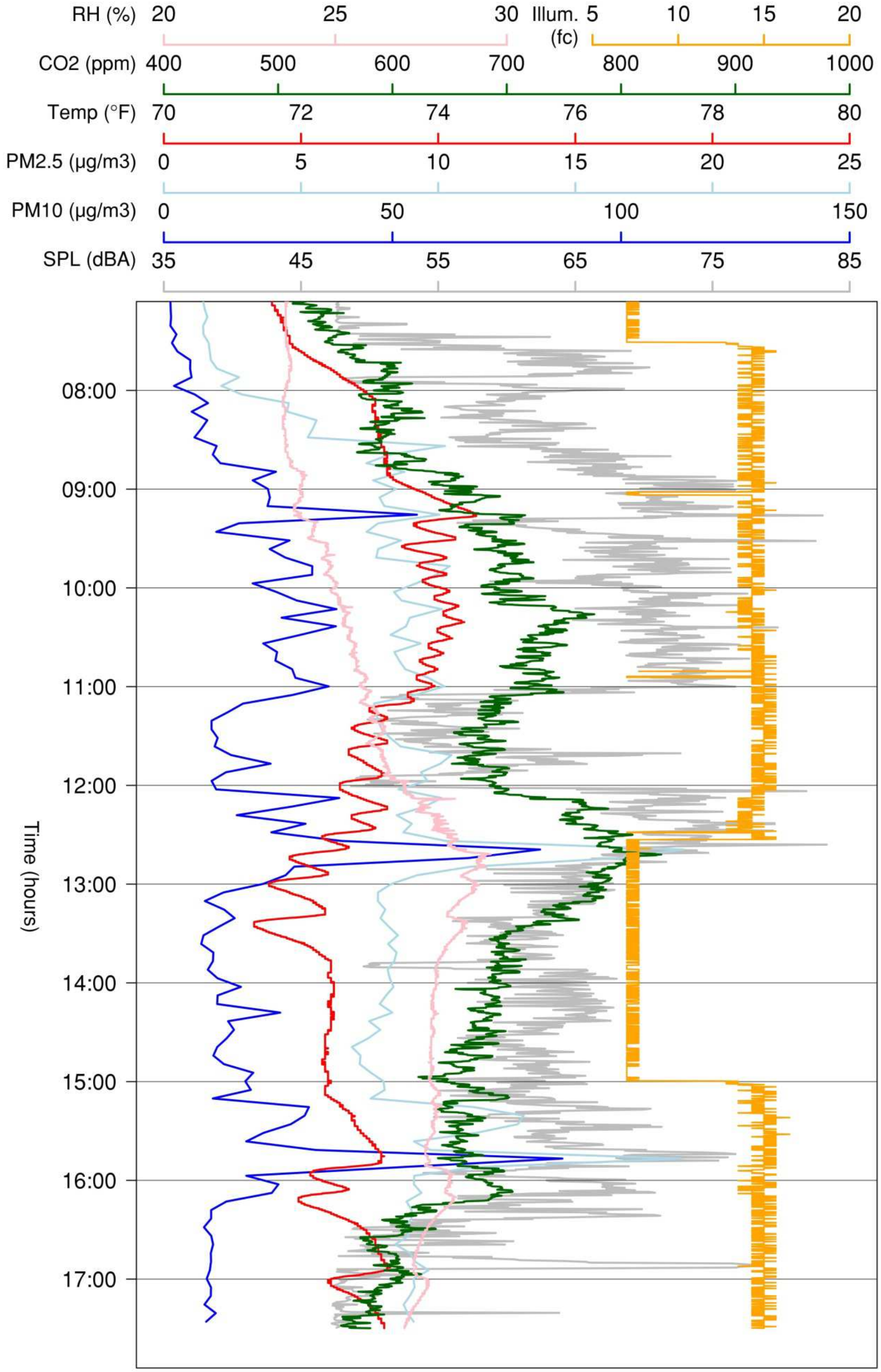

Figure A-4: **Room A38 Measures – 10 Hours**

***Figure A-5*: Room A88 Particulate Matter Concentration 15-Minute TWA – Day 1**

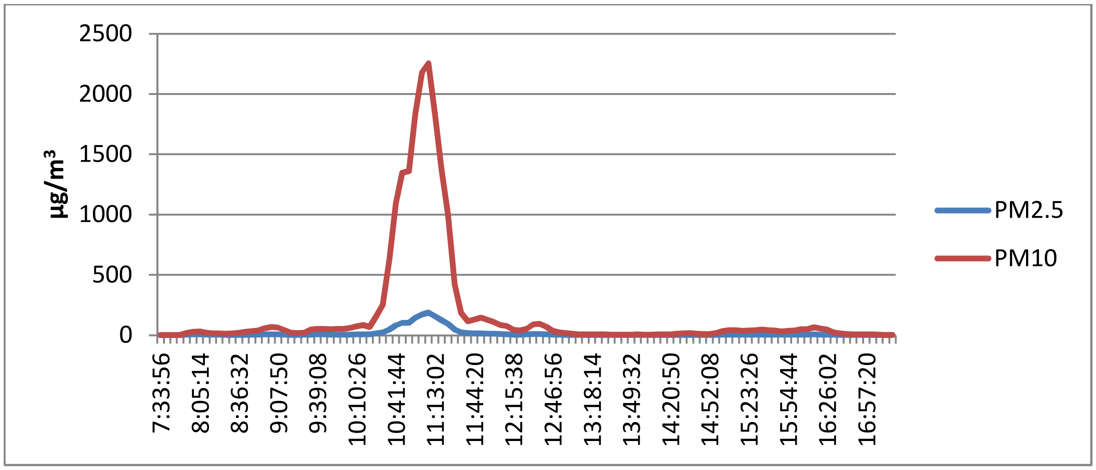

***Figure A-6*: Room A88 Particulate Matter Concentration 15-Minute TWA – Day 2**

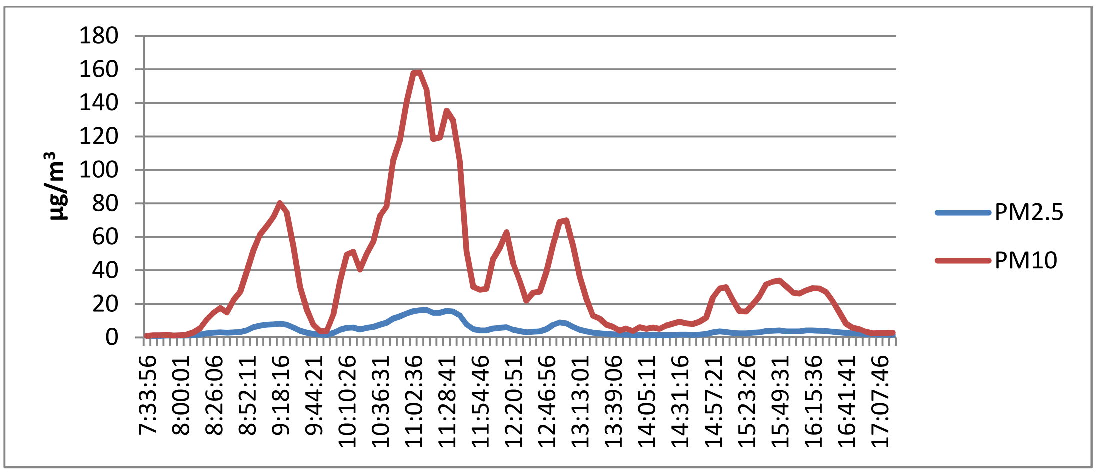

***Figure A-7*: Room A88 Particulate Matter Concentration 15-MinuteTWA – Day 3**

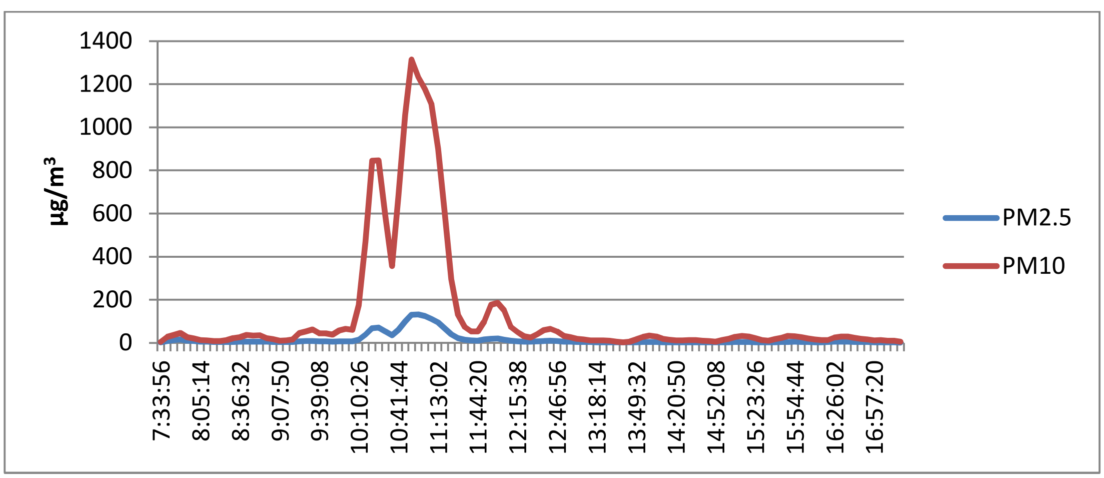

Table A-5: ***Example of Observational Checklist Data***

Room	Area (ft^2)	Color (no warm=-1; >=1 warm=1)	Ext Door	Plants (number)	Blinds (closed=-1; 1/2=0; open=1)	Hiding (places)	Flooring (fraction carpet)	Type (Infant=0; 1-2yrs=1; 2-3yrs=2; 3-5yrs=3)	Acoustic (separation, yes=1)	Switches	Orientation (clockwise degrees from north)	Glare (fraction w/ protection)	Lighting Power Density (LPD)	Illum Avg High	Illum Ratio	Tstat (no=-1; yes but covered=0; yes=1)
-	578	1	0	1	1	0	0.67	1	-1	3.5	0	1	2.52	72.5	1.96	1
-	574	1	0	1	1	2	0.50	2	-1	1.5	0	1	2.21	74.2	1.87	0
-	595	-1	0	1	-1	3	0.50	2	-1	1.5	0	1	2.22	71.2	2.62	0
-	563	1	0	1	0	1	0.60	0	-1	3.5	45	1	2.49	74.2	2.20	1
-	561	1	0	0	0	1	0.60	1	-1	3.5	135	0.75	2.46	76.4	2.86	1
-	881	1	1	1	-1	1	0.15	3	-1	1.5	90	0.85	2.29	85.9	3.02	1
-	850	-1	0	1	1	1	0.13	3	-1	1.5	135	0.6	2.31	97.3	2.92	1
-	889	1	0	1	0	1	0.11	3	-1	1.5	-135	1	2.20	82.2	2.74	1

APPENDIX B - Outcome Variable Data

***Figure B-1*: Lead Teacher Survey Data by Classroom**

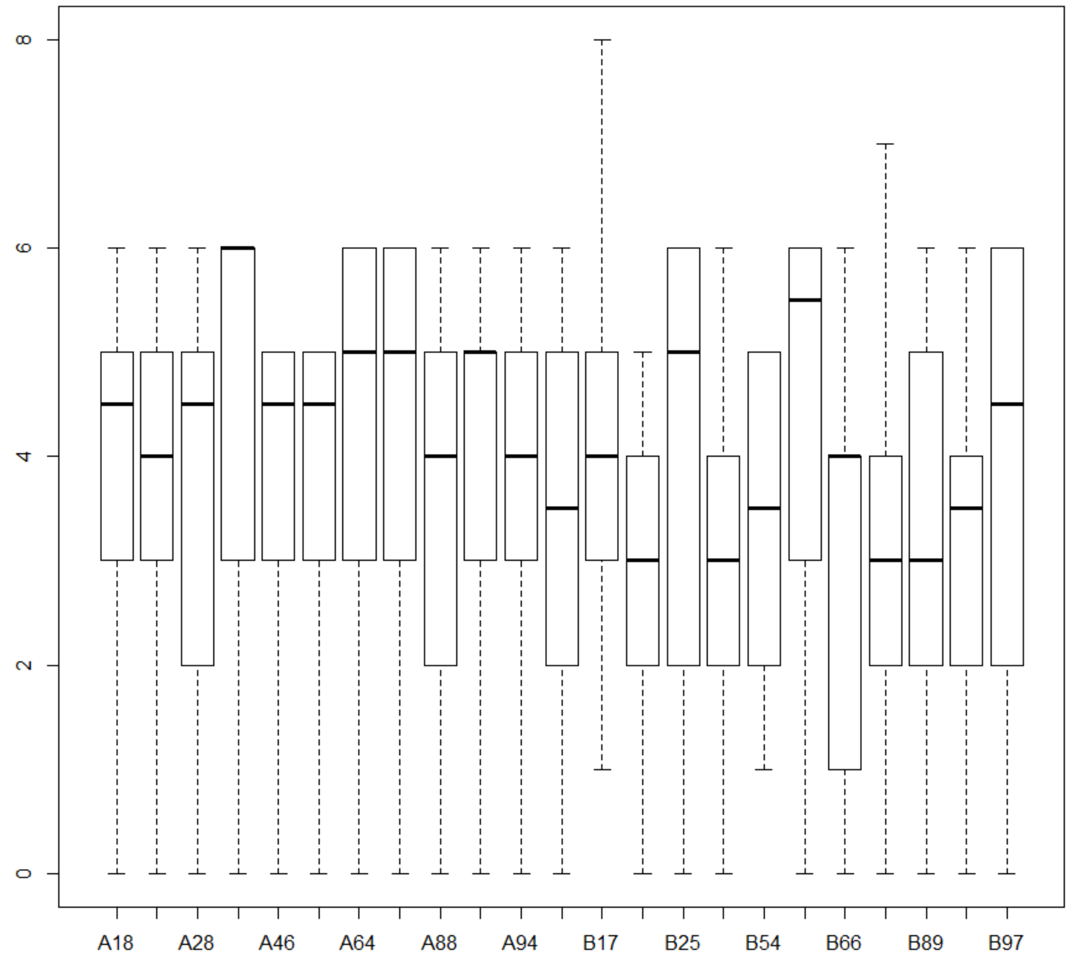

***Figure B-2*: Assistant Teacher Survey Data by Classroom**

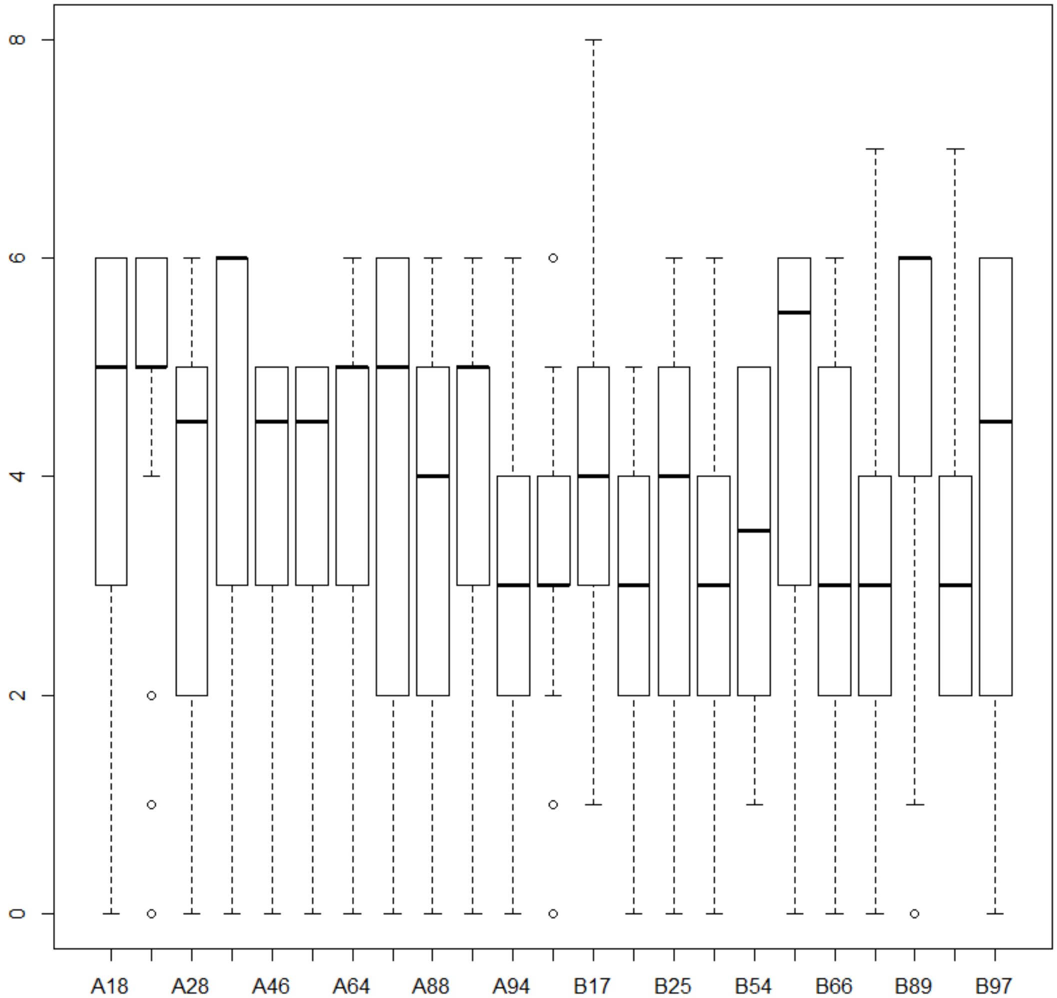

***Figure B-3*: Teacher's Aide Survey Data by Classroom**

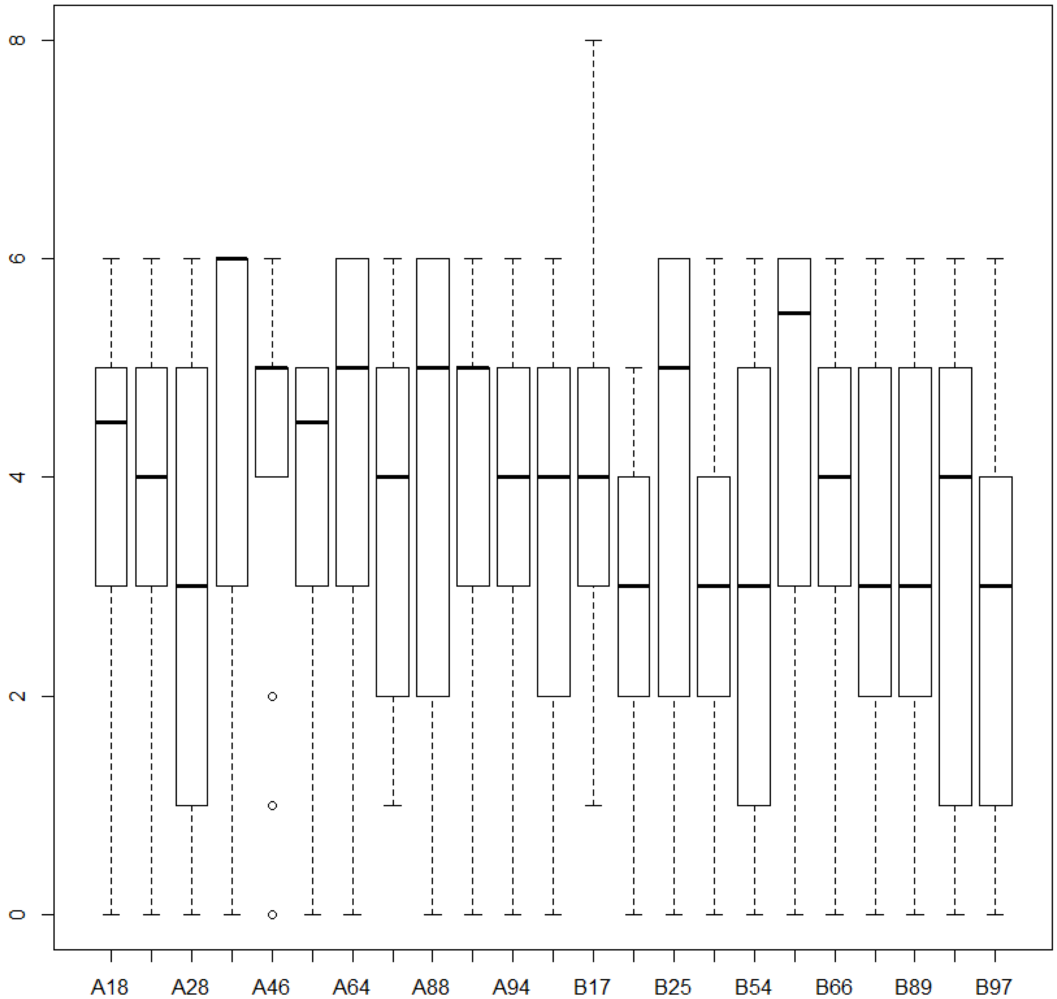

***Figure B-4*: Spearman's Rank Correlation Significance for Survey Items**

Table B-1: ***Lead Teacher Dataset Composite Raw Scores***

classroom	title	tenure	experience	teachage	sizesat	viewsat	accsat2	thermsat	airtot	lighttot	naturaltot	furntot	cleantot	orgsat	ieqoverall
A18	1	2	4	4	4.0	5.0	4.7	4.1	5.7	5.5	5.5	4.5	4.2	3.9	5.0
A19	1	3	3	1	5.0	4.0	5.3	3.6	5.2	3.5	4.5	4.2	3.0	3.3	4.0
A28	2	3	2	1	5.0	5.3	4.0	1.7	3.2	5.5	6.0	4.2	3.3	4.0	5.0
A38	1	3	3	1	5.5	6.0	4.7	3.6	6.0	4.5	5.0	6.0	4.5	3.9	6.0
A46	1	3	1	1	5.0	4.7	5.0	3.4	3.0	3.5	5.0	4.8	4.2	4.0	5.0
A55	1	4	4	2	4.5	5.0	4.7	3.1	4.3	5.5	5.0	5.0	4.0	4.0	5.0
A64	1	4	3	1	5.5	5.3	4.0	3.4	5.2	5.0	5.0	5.8	4.7	3.3	5.0
A66	1	2	1	1	5.0	5.3	4.0	2.6	4.2	3.0	5.0	5.5	5.0	3.0	4.0
A88	1	3	3	1	4.5	3.3	5.0	2.9	5.7	5.5	3.5	5.2	3.5	3.3	4.0
A91	2	4	3	4	5.0	4.7	5.3	6.0	4.7	4.0	5.0	4.7	3.5	2.1	5.0
A94	1	4	4	4	5.0	5.3	4.7	3.1	4.5	5.5	5.5	3.5	3.2	3.3	5.0
B12	1	2	2	2	2.0	4.7	3.7	4.6	5.3	6.0	1.5	4.3	3.0	3.0	5.0
B17	1	3	2	1	4.0	2.7	2.0	2.7	3.2	2.5	2.0	1.5	2.8	3.0	5.0
B19	1	3	2	1	4.0	3.7	4.3	1.9	4.2	5.0	4.5	2.8	2.8	3.3	5.0
B25	1	2	4	2	5.5	5.3	4.3	2.3	5.5	5.5	6.0	5.0	4.3	3.9	6.0
B33	2	3	4	3	4.0	4.7	3.3	1.9	1.0	4.5	5.0	3.0	2.7	3.6	5.0
B54	2	3	4	4	3.0	5.0	5.0	2.7	4.8	4.0	3.0	4.2	2.3	3.3	4.0
B64	1	2	3	2	6.0	6.0	5.3	5.8	5.2	6.0	5.0	5.3	3.8	3.3	5.0
B66	1	2	3	1	2.5	4.3	4.0	3.6	5.3	6.0	5.0	3.5	2.2	3.4	4.0
B81	2	3	4	4	2.5	3.0	2.0	1.3	2.3	4.5	4.0	3.7	2.5	3.3	4.0
B89	1	4	4	4	5.0	3.7	3.7	4.3	3.8	5.5	5.0	4.5	3.0	3.7	4.0
B93	1	2	2	2	2.5	4.0	4.0	3.3	5.7	5.5	3.0	4.2	3.0	2.4	4.0
B97	1	2	3	1	6.0	5.0	5.3	3.3	5.2	6.0	4.0	4.8	4.0	4.0	6.0
μ_A	1.2	3.2	2.8	1.9	4.9	4.9	4.7	3.4	4.7	4.6	5.0	4.8	3.9	3.5	4.8
σ_A	0.4	0.8	1.1	1.4	0.4	0.7	0.5	1.1	1.0	1.0	0.6	0.8	0.7	0.6	0.6
μ_B	1.3	2.6	3.1	2.3	3.9	4.3	3.9	3.1	4.3	5.1	4.0	3.9	3.0	3.3	4.8
σ_B	0.5	0.7	0.9	1.2	1.4	1.0	1.1	1.3	1.5	1.1	1.4	1.1	0.7	0.4	0.8
μ	1.2	2.9	3.0	2.1	4.4	4.6	4.3	3.3	4.5	4.9	4.5	4.4	3.5	3.4	4.8
σ	0.4	0.8	1.0	1.3	1.2	0.9	0.9	1.2	1.2	1.0	1.2	1.0	0.8	0.5	0.7
p $\mu_A \neq \mu_B$	0.708	0.056	0.528	0.535	0.047*	0.118	0.050*	0.557	0.988	0.304	0.040*	0.026*	0.008**	0.670	0.814

Table B-2: ***Summary of Statistical Linear Regression Tests***

Outcome	Model (p < 0.001*** p < 0.01** p < 0.05* *p < 0.1)*		
sizesat	area*** + school**	area*** + *crtype* + *areaXcrtype*	
	area + school* + *areaXschool*	bnllow + *school* + *bnllowXschool*	
	bnllow* + school	bnllow** + *crtype* + *bnllowXcrtype*	
viewsat	illumratio* + *school*		
accsat1	*rh10* + school*		
accsat2	area* + school*	*rt20* + school*	rh10* + *school*
	bnllow + school	*bnlhigh* + school*	
thermsat	crtype* + orient.factor*	school + *orient.factor*	*color* + crtype*
airtot	*onoff10* + school	*co210* + school	*co215* + school
airinterfere	co210* + school	*co215* + school	*tenure*
lighttot	illumratio* + school		
naturaltot	bnllow** + school + orgsat*	bnllow* + school	
	bnldelta** + *orgsat*	area + school* + *areaXschool*	
	illum** + school***	bnllow + *school* + *bnllowXschool*	
	bnldelta + school	bnllow*** + orgsat*	
furntot	*color* + school	co210* + school**	co215* + school**
cleantot	color* + school	area + school** + areaXschool*	
	co210 + school**	*co215* + school**	illum* + school**
ieqoverall	*orgsat* + school	ieqT* + school	*area* + school
	carpet + orgsat*	plants* + orgsat*	rh10* + *orgsat*
ieq.sensory	rh10* + school	*bnllow* + school	area* + school
	carpet* + school	*bnlhigh* + school	*rt20* + school
	illumratio* + school	*illum* + *school*	
ieqT	rt20* + school*	*rh10* + *school*	*hiding*
	area** + school*	illum* + school**	*color*
	carpet + school*	illumratio* + school*	
	bnlhigh + school*	bnllow + school + *bnllowXschool*	
	bnllow* + school	bnlhigh + school* + bnlhighXschool*	

Table B-3: ***Summary of R Software Tests***

SIZE

```
lm(formula = sizesat ~ area, data = survdat1)
             Estimate Std. Error t value Pr(>|t|)
(Intercept) -8.624170   1.900656  -4.537 0.000180 ***
area         0.012123   0.002642   4.588 0.000159 ***

lm(formula = sizesat ~ school + area, data = survdat1)
             Estimate Std. Error t value Pr(>|t|)
(Intercept) -7.791575   1.602665  -4.862 9.45e-05 ***
schoolB     -1.503519   0.467848  -3.214  0.00436 **
area         0.012055   0.002199   5.482 2.29e-05 ***

lm(formula = sizesat ~ school * area, data = survdat1)
               Estimate Std. Error t value Pr(>|t|)
(Intercept)   1.304e+00  4.651e+00   0.280    0.782
schoolB      -1.158e+01  4.904e+00  -2.362    0.029 *
area         -7.115e-04  6.513e-03  -0.109    0.914
schoolB:area  1.415e-02  6.858e-03   2.064    0.053 .

lm(formula = sizesat ~ area * crtype, data = survdat1)
              Estimate Std. Error t value Pr(>|t|)
(Intercept) -16.362211   3.883918  -4.213 0.000471 ***
area          0.024289   0.005845   4.155 0.000537 ***
crtype        3.613591   1.994261   1.812 0.085823 .
area:crtype  -0.005548   0.002751  -2.017 0.058056 .

lm(formula = sizesat ~ bnllow, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  7.78151    2.33659   3.330  0.00318 **
bnllow      -0.20335    0.06048  -3.362  0.00295 **

lm(formula = sizesat ~ bnllow + school, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  7.01668    2.45494   2.858  0.00972 **
bnllow      -0.17353    0.06727  -2.580  0.01789 *
schoolB     -0.72098    0.71337  -1.011  0.32425

lm(formula = sizesat ~ bnllow * crtype, data = survdat1)
              Estimate Std. Error t value Pr(>|t|)
(Intercept)   15.96648    5.22544   3.056  0.00651 **
bnllow        -0.41998    0.13174  -3.188  0.00484 **
crtype        -4.52486    2.39091  -1.893  0.07376 .
bnllow:crtype  0.12446    0.06321   1.969  0.06371 .

lm(formula = sizesat ~ bnllow * school, data = survdat1)
                Estimate Std. Error t value Pr(>|t|)
(Intercept)     0.682768   4.001904   0.171   0.8663
bnllow          0.003195   0.110999   0.029   0.9773
schoolB         9.026129   5.081679   1.776   0.0917 .
bnllow:schoolB -0.261018   0.134898  -1.935   0.0680 .
```

Table B-3: *Summary of R Software Tests*, continued

VIEWS

```
lm(formula = viewsat ~ illumratio, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   -6.532      3.183  -2.052   0.0528 .
illumratio     2.618      1.262   2.075   0.0505 .

lm(formula = viewsat ~ illumratio + school, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  -5.8990     3.0243  -1.951   0.0653 .
illumratio    2.7158     1.1927   2.277   0.0339 *
schoolB      -1.6784     0.8908  -1.884   0.0742 .

lm(formula = ieqoverall ~ viewsat, data = survdat1)
              Estimate Std. Error t value Pr(>|t|)
(Intercept) -3.088e-17  1.821e-01   0.000   1.0000
viewsat      2.155e-01  7.688e-02   2.802   0.0107 *
```

ACOUSTICS

```
lm(formula = rt20 ~ area, data = survdat1)
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 3.060e-01  4.203e-02   7.280 3.61e-07 ***
area        1.699e-04  5.843e-05   2.908  0.00842 **

lm(formula = accsat2 ~ area + school, data = survdat1)
             Estimate Std. Error t value Pr(>|t|)
(Intercept) -6.089350   2.724332  -2.235   0.0370 *
area         0.009922   0.003738   2.654   0.0152 *
schoolB     -1.857325   0.795284  -2.335   0.0301 *

lm(formula = accsat2 ~ rt20 + school, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  -8.7701     5.5360  -1.584   0.1288
rt20         23.3229    13.1594   1.772   0.0916 .
schoolB      -2.2701     0.8878  -2.557   0.0188 *

lm(formula = accsat2 ~ bnllow + school, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  7.09183    3.25630   2.178   0.0416 *
bnllow      -0.17054    0.08922  -1.911   0.0704 .
schoolB     -1.08435    0.94623  -1.146   0.2653

lm(formula = accsat2 ~ bnlhigh + school, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  10.6636     4.9595   2.150   0.0440 *
bnlhigh      -0.2004     0.1019  -1.968   0.0631 .
schoolB      -2.0680     0.8520  -2.427   0.0248 *

lm(formula = accsat2 ~ rh10 + school, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -3.90872    1.89867  -2.059   0.0528 .
rh10         0.21941    0.08126   2.700   0.0138 *
schoolB     -1.63151    0.79691  -2.047   0.0540 .

lm(formula = accsat1 ~ rh10 + school, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  -4.0154     2.9216  -1.374   0.1845
rh10          0.2598     0.1250   2.077   0.0509 .
schoolB      -3.1055     1.2262  -2.533   0.0198 *
```

Table B-3: *Summary of R Software Tests*, continued

```
lm(formula = stcsat ~ laeq10 + school, data = survdat1)
             Estimate Std. Error t value Pr(>|t|)
(Intercept) -13.45338    5.08362  -2.646  0.01549 *
laeq10        0.21448    0.07907   2.713  0.01340 *
schoolB      -1.29382    0.43546  -2.971  0.00755 **
```

TEMPERATURE

```
lm(formula = thermsat ~ crtype, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  -2.2041     1.1640  -1.894   0.0721 .
crtype        1.3701     0.6055   2.263   0.0344 *
```

```
lm(formula = thermsat ~ crtype + school, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  -1.7880     1.3747  -1.301   0.2082
crtype        1.3609     0.6152   2.212   0.0388 *
schoolB      -0.7692     1.2963  -0.593   0.5596
```

```
lm(formula = thermsat ~ orient.factor + crtype, data = survdat1)
               Estimate Std. Error t value Pr(>|t|)
(Intercept)     -1.0072     0.3570  -2.821   0.0105 *
orient.factor1   0.7843     0.3546   2.212   0.0388 *
crtype           0.4141     0.1670   2.480   0.0222 *
```

```
lm(formula = thermsat ~ orient.factor + school, data = survdat1)
               Estimate Std. Error t value Pr(>|t|)
(Intercept)     -0.1695     0.3198  -0.530    0.602
orient.factor1   0.8285     0.4009   2.067    0.052 .
schoolB         -0.3656     0.3979  -0.919    0.369
```

```
lm(formula = thermsat ~ crtype + color, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  -0.3686     0.3614  -1.020   0.3199
crtype        0.4585     0.1726   2.657   0.0151 *
color1       -0.7072     0.3636  -1.945   0.0659 .
```

AIR QUALITY

```
lm(formula = airinterfere ~ tenure, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   1.5138     0.7804   1.940   0.0666 .
tenure       -0.5286     0.2635  -2.006   0.0585 .
```

```
lm(formula = airinterfere ~ co210 + school, data = survdat1)
             Estimate Std. Error t value Pr(>|t|)
(Intercept)  7.290805   3.012798   2.420   0.0257 *
co210       -0.010264   0.004096  -2.506   0.0215 *
schoolB      0.049147   0.411647   0.119   0.9062
```

```
lm(formula = airtot ~ co210 + school, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 14.44811    7.44612   1.940   0.0673 .
co210       -0.01948    0.01012  -1.924   0.0694 .
schoolB     -0.76311    1.01739  -0.750   0.4624
```

Table B-3: *Summary of R Software Tests*, continued

```
lm(formula = airtot ~ co215 + school, data = survdat1)
             Estimate Std. Error t value Pr(>|t|)
(Intercept)  4.234131   2.337779   1.811   0.0860 .
co215       -0.004742   0.002596  -1.827   0.0835 .
schoolB     -0.370674   0.462110  -0.802   0.4324
```

LIGHTING

```
lm(formula = lighttot ~ illumratio + school, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  -4.5780     1.9253  -2.378   0.0275 *
illumratio    1.7105     0.7593   2.253   0.0357 *
schoolB       0.5964     0.5671   1.052   0.3055
```

```
lm(formula = naturaltot ~ area * school, data = survdat1)
               Estimate Std. Error t value Pr(>|t|)
(Intercept)    5.854017   5.577195   1.050   0.3071
area          -0.007198   0.007810  -0.922   0.3683
schoolB      -12.711617   5.880441  -2.162   0.0436 *
area:schoolB   0.015915   0.008224   1.935   0.0680 .
```

```
lm(formula = naturaltot ~ bnllow + school, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  6.46156    2.12290   3.044  0.00641 **
bnllow      -0.16004    0.05817  -2.751  0.01231 *
schoolB     -0.64613    0.61688  -1.047  0.30740
```

```
lm(formula = naturaltot ~ bnllow * school, data = survdat1)
                Estimate Std. Error t value Pr(>|t|)
(Intercept)     0.820939   3.439917   0.239   0.8139
bnllow         -0.002663   0.095411  -0.028   0.9780
schoolB         8.034080   4.368060   1.839   0.0816 .
bnllow:schoolB -0.232447   0.115954  -2.005   0.0595 .
```

```
lm(formula = naturaltot ~ orgsat + bnllow, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  7.18778    1.75019   4.107 0.000548 ***
orgsat       0.14515    0.05103   2.845 0.010017 *
bnllow      -0.18783    0.04530  -4.146 0.000500 ***
```

```
lm(formula = naturaltot ~ orgsat + bnllow + school, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  4.04792    1.12278   3.605  0.00189 **
orgsat       0.40894    0.15052   2.717  0.01368 *
bnllow      -0.10175    0.03079  -3.305  0.00372 **
schoolB     -0.29558    0.32791  -0.901  0.37866
```

```
lm(formula = naturaltot ~ bnldelta + orgsat, data = survdat1)
 (Intercept) -1.15290    0.41113  -2.804   0.01095 *
bnldelta     0.12068    0.03947   3.058  0.00621 **
orgsat       0.34907    0.16917   2.063  0.05229 .
```

```
lm(formula = naturaltot ~ bnldelta + school, data = survdat1)
Estimate Std. Error t value Pr(>|t|)
(Intercept) -1.01086    0.76432  -1.323   0.2009
bnldelta     0.11632    0.05761   2.019   0.0571 .
schoolB     -0.19238    0.48349  -0.398   0.6949
```

Table B-3: ***Summary of R Software Tests*****, continued**

```
lm(formula = naturaltot ~ bnldelta + orgsat + school, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -0.91304    0.71326  -1.280   0.2159
bnldelta     0.10580    0.05389   1.963   0.0644 .
orgsat       0.34866    0.17278   2.018   0.0579 .
schoolB     -0.18727    0.45016  -0.416   0.6821
```

```
lm(formula = naturaltot ~ illum + school, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -4.23798    1.45157  -2.920  0.00847 **
illum        0.09386    0.02875   3.264  0.00388 **
schoolB     -3.73971    0.94274  -3.967  0.00076 ***
```

FURNISHINGS

```
lm(formula = furntot ~ co210 + school, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 33.37299   13.24796   2.519  0.02038 *
co210       -0.04247    0.01801  -2.358  0.02866 *
schoolB     -6.10945    1.80270  -3.389  0.00291 **
```

```
lm(formula = furntot ~ co215 + school, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 24.24878    9.40070   2.579   0.0179 *
co215       -0.02461    0.01044  -2.358   0.0287 *
schoolB     -6.36475    1.85078  -3.439   0.0026 **
```

```
lm(formula = furntot ~ color + crtype, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  0.44390    0.37400   1.187   0.2492
color1      -1.03852    0.37626  -2.760   0.0121 *
crtype       0.06088    0.17858   0.341   0.7367
```

```
lm(formula = furntot ~ color + school, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   0.6808     0.2815   2.419   0.0252 *
color1       -0.7609     0.4074  -1.868   0.0765 .
schoolB      -0.5439     0.4074  -1.335   0.1968
```

```
lm(formula = furntot ~ color, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   0.5325     0.2634   2.022   0.0561 .
color1       -1.0205     0.3646  -2.799   0.0108 *
```

CLEANING

```
lm(formula = cleantot ~ color + school, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept)    3.180      0.999   3.183  0.00467 **
color1        -3.633      1.446  -2.512  0.02068 *
schoolB       -2.462      1.446  -1.702  0.10419
```

```
lm(formula = cleantot ~ illum + school, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -12.4635     5.7405  -2.171  0.04213 *
illum         0.2940     0.1137   2.585  0.01768 *
schoolB     -13.2654     3.7283  -3.558  0.00197 **
```

Table B-3: ***Summary of R Software Tests*****, continued**

```
lm(formula = cleantot ~ rt20 + school, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  -15.817      8.466  -1.868  0.07643 .
rt20          43.074     20.124   2.140  0.04483 *
schoolB       -4.921      1.358  -3.624  0.00169 **
```

```
lm(formula = cleantot ~ co210 + school, data = survdat1)
             Estimate Std. Error t value Pr(>|t|)
(Intercept)  5.992934   2.719206   2.204  0.03941 *
co210       -0.007425   0.003696  -2.009  0.05827 .
schoolB     -1.371766   0.370013  -3.707  0.00139 **
```

```
lm(formula = cleantot ~ co215 + school, data = survdat1)
             Estimate Std. Error t value Pr(>|t|)
(Intercept)  4.510353   1.917939   2.352  0.02905 *
co215       -0.004429   0.002129  -2.080  0.05061 .
schoolB     -1.426843   0.377597  -3.779  0.00118 **
```

```
lm(formula = cleantot ~ area * school, data = survdat1)
              Estimate Std. Error t value Pr(>|t|)
(Intercept)   5.800420   3.129442   1.854  0.07940 .
area         -0.007365   0.004382  -1.681  0.10920
schoolB      -9.550543   3.299597  -2.894  0.00929 **
area:schoolB  0.011931   0.004614   2.586  0.01814 *
```

IEQ OVERALL

```
lm(formula = ieqoverall ~ orgsat + school, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  0.01698    0.29345   0.058   0.9544
orgsat       0.37600    0.20794   1.808   0.0856 .
schoolB     -0.03254    0.40712  -0.080   0.9371
```

```
lm(formula = ieqoverall ~ orgsat + plants, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -0.42438    0.27273  -1.556   0.1354
orgsat       0.09933    0.04021   2.470   0.0226 *
plants       0.39043    0.18581   2.101   0.0485 *
```

```
lm(formula = ieqoverall ~ orgsat + carpet, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  0.58207    0.36295   1.604   0.1245
orgsat       0.08322    0.03980   2.091   0.0495 *
carpet      -1.54665    0.82685  -1.871   0.0761 .
```

```
lm(formula = ieqoverall ~ rh10 + orgsat, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -1.75737    0.83366  -2.108   0.0478 *
rh10         0.08101    0.03750   2.160   0.0431 *
orgsat       0.06834    0.03905   1.750   0.0954 .
```

```
lm(formula = ieqoverall ~ ieqT + school, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  -0.1592     0.2943  -0.541   0.5948
ieqT          0.5452     0.2220   2.456   0.0238 *
schoolB       0.2889     0.4337   0.666   0.5133
```

```
lm(formula = ieq.sensory ~ area + school, data = survdat1)
             Estimate Std. Error t value Pr(>|t|)
(Intercept) -2.950265   1.281645  -2.302   0.0328 *
area         0.004419   0.001759   2.512   0.0212 *
schoolB     -0.367075   0.380520  -0.965   0.3468
```

Table B-3: *Summary of R Software Tests*, continued

```
lm(formula = ieq.sensory ~ illumratio + school, data = survdat1)
             Estimate Std. Error t value Pr(>|t|)
(Intercept)   -3.1256     1.2557  -2.489   0.0222 *
illumratio     1.3413     0.4955   2.707   0.0140 *
schoolB       -0.4061     0.3730  -1.089   0.2899

lm(formula = ieq.sensory ~ illum + school, data = survdat1)
             Estimate Std. Error t value Pr(>|t|)
(Intercept) -2.94543    1.83337  -1.607   0.1246
illum        0.06307    0.03633   1.736   0.0987 .
schoolB     -2.32109    1.18172  -1.964   0.0643 .

lm(formula = ieq.sensory ~ carpet + school, data = survdat1)
             Estimate Std. Error t value Pr(>|t|)
(Intercept)    0.9580     0.4585   2.090   0.0503 .
carpet        -1.8502     0.8839  -2.093   0.0500 *
schoolB       -0.4816     0.3979  -1.211   0.2409

lm(formula = ieq.sensory ~ rh10 + school, data = survdat1)
             Estimate Std. Error t value Pr(>|t|)
(Intercept) -1.80325    0.91209  -1.977   0.0627 .
rh10         0.08982    0.03904   2.301   0.0329 *
schoolB     -0.28800    0.39105  -0.736   0.4704

lm(formula = ieq.sensory ~ bnllow + school, data = survdat1)
             Estimate Std. Error t value Pr(>|t|)
(Intercept)  3.23600    1.63168   1.983    0.062 .
bnllow      -0.08477    0.04483  -1.891    0.074 .
schoolB      0.06358    0.47027   0.135    0.894

lm(formula = ieq.sensory ~ bnlhigh + school, data = survdat1)
             Estimate Std. Error t value Pr(>|t|)
(Intercept)  5.07552    2.42678   2.091   0.0502 .
bnlhigh     -0.10095    0.04989  -2.024   0.0573 .
schoolB     -0.43198    0.39859  -1.084   0.2920

lm(formula = ieq.sensory ~ rt20 + school, data = survdat1)
             Estimate Std. Error t value Pr(>|t|)
(Intercept)   -4.4394     2.6068  -1.703   0.1049
rt20          11.0930     6.1980   1.790   0.0894 .
schoolB       -0.5536     0.4156  -1.332   0.1986

lm(formula = ieqT ~ area + school, data = survdat1)
              Estimate Std. Error t value Pr(>|t|)
(Intercept) -3.105370   1.116866  -2.780  0.01192 *
area         0.004905   0.001533   3.200  0.00471 **
schoolB     -0.746680   0.331597  -2.252  0.03636 *

lm(formula = ieqT ~ illumratio + school, data = survdat1)
             Estimate Std. Error t value Pr(>|t|)
(Intercept)   -2.6213     1.1907  -2.202   0.0403 *
illumratio     1.2151     0.4699   2.586   0.0181 *
schoolB       -0.7878     0.3537  -2.228   0.0382 *

lm(formula = ieqT ~ illum + school, data = survdat1)
             Estimate Std. Error t value Pr(>|t|)
(Intercept) -3.78687    1.57334  -2.407  0.02642 *
illum        0.08379    0.03117   2.688  0.01457 *
schoolB     -3.33652    1.01412  -3.290  0.00385 **
```

Table B-3: *Summary of R Software Tests*, continued

```
lm(formula = ieqT ~ rt20 + school, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  -5.0169     2.3259  -2.157   0.0440 *
rt20         12.9323     5.5300   2.339   0.0304 *
schoolB      -0.9625     0.3708  -2.596   0.0177 *

lm(formula = ieqT ~ color + crtype, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  0.00131    0.38182   0.003   0.9973
color1      -0.90520    0.39189  -2.310   0.0323 *
crtype       0.27579    0.18348   1.503   0.1493

lm(formula = ieqT ~ carpet + school, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   1.0713     0.4335   2.471   0.0231 *
carpet       -1.6600     0.8357  -1.986   0.0616 .
schoolB      -0.8555     0.3762  -2.274   0.0347 *

lm(formula = ieqT ~ rh10 + school, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -1.13237    0.89395  -1.267   0.2206
rh10         0.06829    0.03826   1.785   0.0903 .
schoolB     -0.69652    0.38327  -1.817   0.0850 .

lm(formula = ieqT ~ bnllow + school, data = survdat1)
Estimate Std. Error t value Pr(>|t|)
(Intercept)  3.53717    1.49577   2.365   0.0288 *
bnllow      -0.08783    0.04109  -2.137   0.0458 *
schoolB     -0.30257    0.43110  -0.702   0.4913

lm(formula = ieqT ~ bnlhigh + school, data = survdat1)
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  4.57847    2.31168   1.981   0.0623 .
bnlhigh     -0.08671    0.04752  -1.825   0.0838 .
schoolB     -0.80959    0.37968  -2.132   0.0463 *

lm(formula = ieqT ~ bnlhigh * school, data = survdat1)
                Estimate Std. Error t value Pr(>|t|)
(Intercept)      0.91059    2.58780   0.352   0.7290
bnlhigh         -0.01079    0.05333  -0.202   0.8419
schoolB          9.30145    4.28132   2.173   0.0434 *
bnlhigh:schoolB -0.21027    0.08875  -2.369   0.0292 *

lm(formula = ieqT ~ bnllow * school, data = survdat1)
                Estimate Std. Error t value Pr(>|t|)
(Intercept)     0.279978   2.269096   0.123   0.9032
bnllow          0.003047   0.062937   0.048   0.9619
schoolB         5.245236   3.054251   1.717   0.1031
bnllow:schoolB -0.146400   0.079881  -1.833   0.0834 .
```

APPENDIX C - Participant Survey

Nebraska UNIVERSITY OF Lincoln

THE DURHAM SCHOOL of ARCHITECTURAL ENGINEERING and CONSTRUCTION

Offering Programs in Omaha and Lincoln
COLLEGE OF ENGINEERING

PARTICIPANT SURVEY

UNL IRB# 14840

Study Title: Effect of the physical environment on teacher satisfaction with indoor environmental quality.

Name:

School:

Classroom Number:

Job Title:
□ Lead Teacher
□ Associate Teacher
□ Teacher's Aide
□ Other _______________

How long have you taught in this classroom?
□ less than 3 months □ 3 – 12 months □ 1 – 3 years □ more than 3 years

How many years total have you been teaching?
□ less than 1 year □ 1 – 3 years □ 3 – 10 years □ more than 10 years

What is your age?
□ 30 or under □ 31 – 40 □ 41 – 50 □ over 50

What is your gender?

Do you have a condition that impacts your vision? Please describe.

Do you have a condition that impacts your hearing? Please describe.

Do you have a condition that impacts your sense of smell? Please describe.

The Charles W. Durham School of Architectural Engineering and Construction
The Peter Kiewit Institute / 1110 South 67th Street / Omaha, NE 68182-0816 / 402-554-2460 / www.durhamschool.unl.edu

CLASSROOM SIZE

How satisfied are you with the amount of space available for your use and storage?

Very Dissatisfied ☹ ☐—☐—☐—☐—☐—☐ ☺ Very Satisfied

How satisfied are you with the amount of space available for children?

Very Dissatisfied ☹ ☐—☐—☐—☐—☐—☐ ☺ Very Satisfied

Does the classroom size interfere with your ability to do your job?

Interferes ☹ ☐—☐—☐—☐—☐—☐ ☺ Does not Interfere

Are there other issues with classroom size?

CLASSROOM VIEWS

How satisfied are you with the ability communicate with and see your co-workers?

Very Dissatisfied ☹ ☐—☐—☐—☐—☐—☐ ☺ Very Satisfied

How satisfied are you with the privacy of your classroom from the outdoors and hallway?

Very Dissatisfied ☹ ☐—☐—☐—☐—☐—☐ ☺ Very Satisfied

How satisfied are you with the quality of views to the outdoors and nature?

Very Dissatisfied ☹ ☐—☐—☐—☐—☐—☐ ☺ Very Satisfied

Do the classroom views interfere with your ability to do your job?

Interferes ☹ ☐—☐—☐—☐—☐—☐ ☺ Does not Interfere

Are there other issues with the classroom views?

ACOUSTICS

How satisfied are you with the sound level (quietness or loudness) in your classroom?

Very Dissatisfied ☹ ☐—☐—☐—☐—☐—☐ ☺ Very Satisfied

How satisfied are you with the ability to keep noise from other spaces out of your classroom?

Very Dissatisfied ☹ ☐—☐—☐—☐—☐—☐ ☺ Very Satisfied

How satisfied are you with the ability for the children to understand you without having to speak louder?

Very Dissatisfied ☹ ☐—☐—☐—☐—☐—☐ ☺ Very Satisfied

Which of the following create noise problems? (check all that apply)

- ☐ Children in the classroom
- ☐ People in other classrooms
- ☐ People in the hallway
- ☐ Lights (buzzing)
- ☐ Heating and cooling system
- ☐ Outdoor noise
- ☐ Alarms / testing
- ☐ Anouncement system or phones
- ☐ Other:

Do the acoustics interfere with your ability to do your job?

Interferes ☹ ☐—☐—☐—☐—☐—☐ ☺ Does not Interfere

Are there other issues with the acoustics?

TEMPERATURE

Which of the following can you personally control in your classroom? (check all that apply):

- ☐ Thermostat
- ☐ Portable Heater
- ☐ Portable Fan
- ☐ Door to hallway
- ☐ Door to outdoors
- ☐ Other:

How satisfied are you with the temperature for your comfort in the classroom?

Very Dissatisfied ☹ ☐—☐—☐—☐—☐—☐ ☺ Very Satisfied

How satisfied are you with the temperature for the children's comfort in the classroom?

Very Dissatisfied ☹ ☐—☐—☐—☐—☐—☐ ☺ Very Satisfied

Check all that apply about the temperature:

- ☐ Too cold
- ☐ Too hot
- ☐ It is worse in the morning
- ☐ It is worse in the afternoon
- ☐ Too much air movement / blowing from diffusers
- ☐ Too little air movement / a fan would help
- ☐ It is drafty or cold around windows
- ☐ Thermostat does not work
- ☐ Thermostat is controlled by someone else

Does the temperature interfere with your ability to do your job?

Interferes ☹ ☐—☐—☐—☐—☐—☐ ☺ Does not Interfere

Are there other issues with the temperature?

AIR QUALITY

How satisfied are you with the air quality in your classroom? (stuffy air, odors, dusty)

Very Dissatisfied ☹ ☐—☐—☐—☐—☐—☐ ☺ Very Satisfied

Which of the following contribute to odor problems? (check all that apply):

- ☐ Cleaning products
- ☐ Outside pollution (cars, tobacco smoke)
- ☐ Perfume
- ☐ Furniture
- ☐ Manipulatives / Toys
- ☐ Plants or Aquarium
- ☐ Other people
- ☐ Food

Does the air quality interfere with your ability to do your job?

Interferes ☹ ☐—☐—☐—☐—☐—☐ ☺ Does not Interfere

Are there other issues with the air quality?

LIGHTING

Which of the following can you personally control in your classroom? (check all that apply):

- ☐ Light switch
- ☐ Light dimmer
- ☐ Window blinds or shades
- ☐ Floor or desk lamps
- ☐ None of the above
- ☐ Other:

How satisfied are you with the electric light in your classroom?

Very Dissatisfied ☹ ☐—☐—☐—☐—☐—☐ ☺ Very Satisfied

Check all that apply about the electric light:

- ☐ Too dark
- ☐ Too bright
- ☐ Lights flicker
- ☐ Hurts my eyes
- ☐ In the wrong place

How satisfied are you with the daylight (natural light) in your classroom?

Very Dissatisfied ☹ ☐—☐—☐—☐—☐—☐ ☺ Very Satisfied

Check all that apply about the daylight:

- ☐ Not enough windows
- ☐ Too many windows
- ☐ The shades are almost always closed
- ☐ Shades don't work / too hard to use
- ☐ Sunlight is too bright at times (glare)

Does the lighting interefere with your ability to do your job?

Interferes ☹ ☐—☐—☐—☐—☐—☐ ☺ Does not Interfere

Are there other issues with the lighting?

FURNITURE

How satisfied are you with the comfort of furniture for adults?

Very Dissatisfied ☹ ☐—☐—☐—☐—☐—☐ ☺ Very Satisfied

How satisfied are you with the comfort of furniture for children?

Very Dissatisfied ☹ ☐—☐—☐—☐—☐—☐ ☺ Very Satisfied

How satisfied are you with the ability to adjust and move the furniture to meet your needs?

Very Dissatisfied ☹ ☐—☐—☐—☐—☐—☐ ☺ Very Satisfied

How satisfied are you with the organization and layout of furniture in the classroom?

Very Dissatisfied ☹ ☐—☐—☐—☐—☐—☐ ☺ Very Satisfied

How satisfied are you with the colors and textures of flooring, furniture, and walls?

Very Dissatisfied ☹ ☐—☐—☐—☐—☐—☐ ☺ Very Satisfied

Does the furniture interfere with your ability to do your job?

Interferes ☹ ☐—☐—☐—☐—☐—☐ ☺ Does not Interfere

Are there other issues with the furniture?

CLEANING AND ORGANIZATION

How satisfied are you with the tidiness of your classroom?

Very Dissatisfied ☹ ☐—☐—☐—☐—☐—☐ ☺ Very Satisfied

How satisfied are you with the cleaning service in your classroom?

Very Dissatisfied ☹ ☐—☐—☐—☐—☐—☐ ☺ Very Satisfied

How satisfied are you with the wall display surfaces?

Very Dissatisfied ☹ ☐—☐—☐—☐—☐—☐ ☺ Very Satisfied

Which of the following are problems?

- ☐ Not enough storage for manipulatives / toys
- ☐ Manipulatives / toys are not put away
- ☐ Too many items displayed on walls
- ☐ Not enough items displayed on walls
- ☐ Not enough trash cans / in the wrong place
- ☐ Furniture is difficult to clean
- ☐ Floor is dusty or dirty
- ☐ Hard to control dirt from playground
- ☐ Furniture and countertops are dusty or dirty
- ☐ Too many items on countertops / cabinets
- ☐ Carpet is not properly cleaned

Does cleaning and organization interfere with your ability to do your job?

Interferes ☹ ☐—☐—☐—☐—☐—☐ ☺ Does not Interfere

Are there other issues with cleaning?

WORK ENVIRONMENT

How much do you agree or disagree with the following statements?

	Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree
I enjoy my work.	☐	☐	☐	☐
My team works well together.	☐	☐	☐	☐
My employer invests to make me more successful.	☐	☐	☐	☐
I am paid fairly.	☐	☐	☐	☐
I understand the purpose of my organization.	☐	☐	☐	☐
It would take a lot to get me to leave this job.	☐	☐	☐	☐
I have a trusting relationship with one or more co-workers.	☐	☐	☐	☐

OVERALL

All things considered, how satisfied are you with your classroom?

Very Dissatisfied ☹ ☐—☐—☐—☐—☐—☐ ☺ Very Satisfied

End of Survey – Thank you!