THE LINK BETWEEN HVAC TYPE AND STUDENT ACHIEVEMENT

Ana Maria Jaramillo

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Michael G. Ermann, Co-Chair

Patrick A. Miller, Co-Chair

Glen I. Earthman

Georg Reichard

Robert P. Schubert

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ABSTRACT

Researchers and practitioners have found that the type of mechanical system utilized to thermally condition a space impacts the noise level for occupants. Indeed, in schools, air conditioning systems are by far the largest contributors to room noise (Bradley, 2002; Nelson et al., 2005; Siebein et al., 2000). Studies have also demonstrated the impact of noise on youth's cognitive performance. The problem is worsened in non-native speakers and children with hearing loss (which can be temporary due to colds and allergies or permanent). No studies yet have bridged those two widely-supported findings: if the type of mechanical system impacts (and often dictates) the noise level in the room, and if the noise level in the room impacts the performance of the student, might there be a correlation between mechanical system type and student achievement? An examination of 73 elementary schools in a single Orlando, Florida school district suggests that, for schools populated with students of similar socio-economic background, schools cooling with the noisiest types of mechanical system, with both a compressor and fan exposed to the room, underperformed on standardized student achievement tests relative to those with quieter types of systems. Also, schools with the highest percentages of low socio-economic level children are more likely to get the noisiest type of cooling system. Mechanical system data was gathered through an online survey answered by facility maintenance managers and school percentage student achievement scores on the Florida Comprehensive Assessment Test (FCAT) were obtained from public online data for years 2003 to 2010 for third grade only. This is the earliest students are tested by the FCATs and studies show a larger impact of noise at an early age. This study examined as well the extent to which teachers believe noise from mechanical systems has an effect on student learning and under what conditions. Results from an online survey sent to third grade teachers in the same schools show that teachers generally judge noise levels in their

classroom to be sufficiently quiet and do not consider noise to be a problem that needs addressing. However, in open-ended questions teachers demonstrated an understanding of the effects of noise in children's concentration and classroom speech communication.

DEDICATION

This work is dedicated to my family. My parents, who have supported me every step of the way and encouraged me to always look ahead. My dad, my hero, who makes me believe I am so much more. My mom, my role model, whose words are always the right ones, whose voice radiates the energy necessary to continue. My brothers, always having my back and giving me reasons to never give up. Believing that I can even when I doubt it. Most especially, this work is dedicated to my amazing husband, my soul mate, my best friend. The journey that we took together, to another country, to face a new challenge, would never have been the same alone. He has been there every step of the way, always my biggest fan, always my home. I now look back and see how many times I was able to let myself go just because I knew my family would never let me fall. As I rise now, having achieved my goal, there are no words for all of you…

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LIST OF ABREVIATIONS

ADD	Attention deficit disorder
ADHD	Attention deficit hyperactivity disorder
AHU	Air handling unit
ANSI	American National Standards Institute
ASA	Acoustical Society of America
ASHA	American Speech-Language-Hearing Association
DX	Direct expansion
ESL, ELL	English as a second language, English language learner
FCAT	Florida Comprehensive Assessment Test
FCU	Fan-coil unit
HVAC	Heating, ventilation and air conditioning
IRB	Institutional Review Board
JASA	Journal of the Acoustical Society of America
LSHSS	Language Speech and Hearing Services in Schools
NC	Noise Criteria
OM	Otitis media
POMA	Proceedings of Meetings on Acoustics
RASTI	Rapid speech transmission index
RT	Reverberation time
SBS	Sick building syndrome
SNR	Signal to noise ratio
SPL	Sound pressure level

CHAPTER 1. INTRODUCTION

Classroom design has changed through history along with the evolution of teaching styles. It is common in the present time to find classrooms where learning occurs by exploration more than by lecture-like processes. Open floor classrooms, modular classrooms, traveling classrooms, are some of the newer versions of this educational space and these come with new requirements. However, the learning process, regardless of the task difficulty, is not a mechanical one. It requires a mental process, including cognition, attention (concentration) and discipline. Distractions can be detrimental to learning. In the past, school planners, designers and builders have paid little attention to the topic of classroom acoustics.

Most of the learning activities that occur at school settings require oral communication (teacher-student or student-student), and these activities call for appropriate room acoustics. Previous studies (Crandell & Bess, 1987; Elliott, 1979, 1982; Nabelek & Robinson, 1982) have concluded that children, when compared to adults, have:

- Inefficient, broadband listening strategy.
- Inability to put together missing pieces from speech.
- Immature weighting of acoustic information.
- Increased susceptibility to distracters.
- Decreased ability to segregate signals from noise.
- Higher effects from reverberation.

For these reasons, it is expected that children need better acoustic conditions to fully understand speech.

Noise is defined as *unwanted sound*; background noise is the sum of all noise sources that are part of a setting. There are several types of noise sources present in an educational environment:

- Community noise: sources that are outside the building and come from outdoor activities, such as: pets, traffic, and lawn equipment.
- Activity noise: created by activities in adjacent rooms and corridors, as well as inside the classroom that is not the signal of interest (moving, talking out of place).
- Mechanical noise: produced by the mechanical systems of the building. This type of source is the only type that is regular and consistent, with seasonal variations.

Noise has been found by many researchers to have an effect in different areas of human performance, ranging from office work to memory tasks and school achievement tests. Studies show that the primary source of background noise in classrooms is from the heating, ventilating, and air-conditioning systems (Nelson et al., 2005; Siebein et al., 2000) or mechanical noise. Mechanical noise is important then in the assessment of a classroom's background noise, and it is important to consider that it is usually constant (even though it cycles during the day there is always the need for ventilation even when no temperature adjustment is required) and broad band[1]. The second most common source is noise from traffic on adjacent highways (Acoustical Society of America [ASA], 2002; American National Standards Institute [ANSI], 2002), however, most schools in the United States are located in rural (31% of elementary schools) or semi-urban regions (40%) and away from heavy traffic roads so this is not such a prominent issue (Keaton, 2012).

In the presence of high levels of background noise, human beings have other resources to better understand the signal of interest. Those can be visual cues, previous knowledge of the topic, or mental ability to "fill in the blanks" in the received speech. The last two, are abilities that come with age and experience.

The purpose of this research is to identify the relationship between cooling HVAC type in a school and student achievement, using information about the mechanical systems used at different schools and the state achievement tests. It is expected as a result

[1] A broad band noise is that one composed of a wide range of frequencies.

of this research to advance the discussion in the field with the hope of having an effect on policy making.

Teachers, principals and school district administrators are often not aware of the impact of many of the physical features of a school building and the impact in student achievement. In some cases it is because adults are less affected by these conditions (for example, noise in the classroom) than children, and in some cases it might be simply that they have grown used to the spaces in which they work and don't think twice about their quality. Standardized test scores are a tool to compare achievement in the schools belonging to a district or a state and are often tied to decisions such as funding and resources. This is one of the reasons why tying achievement to noise in the classroom might give school stakeholders a second thought and an additional motive to look for solutions to background noise problems. The goal of this research is then to provide more tools to non-acoustic people to take part in improving the acoustics of classrooms and to take an active stand in the importance of high quality school facilities.

There are presently more than 50 thousand elementary schools in the US educating about 20 million children (Keaton, 2012). Half of them are eligible for free or reduced lunch and as we will present in this study, these children's achievement is already impacted by their low socio-economic status.

This dissertation follows the manuscript format composed by two journal articles. Chapter 2 will introduce a review of previous studies in the field of classroom design and student achievement, classroom acoustics and other related areas. Chapter 3 is composed of the first article, written for submission to the Journal of the Acoustical Society of America (JASA). It presents data, analysis and results obtained from a survey of mechanical systems from elementary schools in Orlando, Florida and touches on a second survey of teachers attitudes towards noise in the classroom from the same district's third grade teachers. Chapter 4 is an article written for submission to the Journal of Speech and Hearing Services in Schools. It presents detailed results from the teacher survey mentioned in the previous chapter. To complement the body of this dissertation several appendices have been included. Appendix A presents a pilot study developed to understand the acoustic conditions of an elementary school, also published in the POMA journal in 2012 after being presented at the 2nd Pan American/Iberian Meeting on Acoustics (Joint with the 160th Meeting of the Acoustical Society of America, 7th Iberoamerican Congress on Acoustics and 17th Mexican Congress on Acoustics) which received the best student paper award. It presents results of measurement and analysis of two third grade elementary school classrooms in Montgomery County, Virginia. Appendix B presents the HVAC survey and Appendix C the teacher survey. Appendix D shows the distribution of data used for this study and possible relationships found between variables, not mentioned in the body of the dissertation. Finally Appendix E is the Institutional Review Board (IRB) approval of appropriate use of human subjects for research.

CHAPTER 2. LITERATURE REVIEW

2.1. Student Achievement

Achievement scores are the tool used by the state to assess learning in the schools, learning being much more complex and difficult to evaluate. The learning process takes place in the schools and there are factors affecting the process that range from family background and teacher quality to age and maintenance of the school building.

2.2. The Physical Environment for Learning

Newman (2009) said:

> There is strong evidence that physical elements such as air quality, temperature and acoustics, have a tangible effect on learning and should therefore be taken into account from the earliest stages in the design process (as cited in Jacobs, 2009, p. 2).

Those elements related to the school facility can be designed properly to not hinder but facilitate learning and the successful achievement set by the state standards. Earthman (2002) found that the most influential building features in student achievement are thermal, lighting, acoustics and age of the building. The latter encompassing in part the other three plus some additional features that the building would lack if it has not undergone any renovations during a long time. Some features are considered necessary to provide a controlled ideal learning environment for the children to learn. These were not used many years ago and are still not used in developing countries, even with extreme thermal conditions and noisy urban environments. One would wonder if these less favored children have adapted to the less than ideal conditions or if only children growing under the controlled settings are prone to suffer from the lack of them.

2.2.1. Age

An old building that has not gone through a major renovation might show significant deterioration and the lack of modern features to provide a more controlled environment. The condition of the building itself has been found to have an effect in student performance (Cash, 1993; Earthman, 1998) as well as teacher performance (Lowe, 1990). The deterioration of the school facility has an impact not only on the students but also on the teacher's performance, which would also be reflected ultimately in the student's performance (Earthman, 2002).

2.2.2. Thermal

High temperatures were found by Harner (1974) to affect school activities such as mathematical skills and reading comprehension (as cited in Earthman, 2002). Three decades later Wargocki & Wyon (2007) found similar results. Lanham (1999) found thermal conditions to have the most effect on student achievement, out of all building features. Kevan & Howes (1980) also found a direct relationship between temperature and student performance, but clarify that clothing, task and acclimatization need to be taken into account when setting comfort temperatures in classrooms. Very high temperatures were also related with a decrease of mental performance (Bell & Baron, 1976).

2.2.3. Lightning

In the late 1960's, fluorescent lighting was available decreasing the need for solar light; classrooms began to be designed in a more compact way with grouped classrooms and few windows for energy savings on air conditioning bills and limited distractions (Heschong, 1999). Weinstein (1979) reports that no effect of windows in the classrooms was found, after comparing the results of windowless classrooms with those that had windows. It wasn't until 1992 that Kuller & Lindsten's study showed statistical evidence of the need of windows in the classroom. In the past decades there has been a movement back to the "spread out" design of schools, with solar orientation in mind, and nature views, but there remain many schools built during the 70's and 80's that did not consider these characteristics as necessary. Heschong (1999, 2003) found that students progressed at least 15% faster on math and reading if they had good daylight in the classroom. Similar results were found by other studies (Nicklas & Bailey, 1995; Plympton, Conway & Epstein, 2000). It is not too clear though what the advantage of daylighting over electric lighting is beyond the general assumptions of better quality light and psychological effects of natural light exposure. Related to the study of daylight it was also found that students who had operable windows in the classroom performed better (Heschong, 1999).

A good quality and distribution of artificial lighting is also important. Older schools might have a system that has been retrofitted without using the lamps that were intended when designed. The effects of a poorly illuminated room could be such as those produced by jetlag (Tanner, 2000).

During her address to the Massachusetts Court, Jacobs (2009) cites a number of studies (Alexander, 1977; Benya, 2001, 2003; Guzowski, 2000; Harding, 1994; Kluth, 2004; Thompson, 1999) relating lighting to health, such as circadian rhythms, production of vitamin D, mood swings, depression, headaches, epilepsy, ADHD and autism exacerbation.

2.2.4. Space

Overcrowding is another physical variable that has an effect in a classroom not only due to the space limitations to the students, but also due to the lack of individual attention that the teacher can provide to each student (Aiello, Nicosia & Thompson, 1979; Earthman, 2002; Fernandez & Timpane, 1995; Rivera-Batiz & Marti, 1995). Additionally, small class size has been found beneficial to learning (Finn & Achilles, 1999).

2.2.5. Air Quality

When the quality of indoor air is poor it is said that the building is suffering from Sick Building Syndrome (SBS). This can cause headaches, respiratory diseases, colds and other illnesses. When a building is suffering from SBS its occupants can lower their productivity up to a 5% (Mull, 1998). Illness and reduced attendance are also related with poor indoor air quality in the classroom (Heath & Mendell, 2004).

2.2.6. Classroom Acoustics

Vern Knudsen and Cyril Harris stated that:

> The school was established to promote learning, which is acquired largely by word of mouth and listening. Therefore, acoustics is one of the most important physical properties that determine how well the school building can serve its primary function. Thus, the exclusion of noise and the reduction of reverberation are indispensable in adapting classrooms to the function of oral instruction (1950).

Classroom acoustics has been considered by acousticians as a very important topic since the 1950's. As far back as 1917, Morgan concluded that noise distraction interfered with learning and that students reported being tense in noisy classrooms. Laird (1930) concluded that students learn more when the classroom noise level is reduced to 40 decibels. Researchers have suggested that unoccupied classroom noise levels should not exceed 35 dB(A) (Bess, Sinclair and Riggs, 1984; Crandell & Smaldino, 1994; Nelson & Soli, 2000). In 1995 the American Speech-Language-Hearing Association (ASHA) recommended that unoccupied classroom noise levels should not exceed 30 dB, reverberation time (RT)[2] should not exceed 0.4 seconds and signal-to-noise ratio (SNR)[3] should be of at least 15 dB. But it wasn't until 2002 that the ANSI standard number 12.60 was published, dictating the first parameters for good classroom acoustics in the United States. It recommended a maximum background noise level of 35 dB(A) and maximum RT of 0.6 s (Nelson, 2000).

[2] Reverberation time is the time in seconds it takes for a sound to decay 60 decibels once the source has stopped emitting it.
[3] Signal to noise ratio is the difference in decibels between the sound pressure level of a sound signal and that of all added background noise sources.

Multiple studies have shown empirical data assessing the importance of background noise, signal to noise ratio (SNR) and reverberation time (RT) in educational spaces (Cohen et al., 1980; Cohen et al., 1981; Duffy, 1992; Hyatt, 1982; Zentall & Shaw, 1980). A study completed by the Department of Health Services in California (1981) investigated the relationship between student performance and classroom and community noise. Achievement scores have been found to be affected by noise in previous studies (Haines, Stansfeld, Head & Job, 2002; Shield & Dockrell, 2007, 2008, 2009), and noise has been concluded to have an effect on school performance by many more (Bronzaft, 1981; Bronzaft & McCarthy, 1975; Crandell & Smaldino, 2000; Dockrell & Shield, 2006; Evans & Maxwell, 1997; Green, Pasternak & Shore, 1982; Hetu, Truchon-Gagnon & Bilodeau, 1990; Hygge, 2000; Hygge, Boman & Enmarker, 2003; Hygge, Evans & Bullinger, 2002; Johansson, 1983; Maxwell & Evans, 2000; Shield & Dockrell, 2007, 2008)

One possible reason why little attention has been given to the noise problem in school settings is the assumption that children are noisy, thus it is normal that classrooms are noisy (Manlove, Frank & Vernon-Feagans, 2001)

Studies show that an adult with normal hearing ability needs a SNR of 6 to 10 dB to understand speech in a noisy setting (Houtgast, 1981). As expected, later studies showed that the ratios needed for children were considerably higher, being about 15 to 20 dB (Bradley, 1986; Hodgson, 1999; Nelson & Soli, 2000). Understanding speech in noise apparently is a skill that develops well into a child's adolescent years and becomes adult-like at approximately age 15 (Elliott, 1979; Johnson, 2000). The same comparison occurs for children with permanent or temporary hearing loss, increasing the ratios even more (Crandell & Smaldino, 1994; Hodgson, 1999). Nelson & Soli (2000) conclude in their review that at any time of the year there are children in the classroom with temporary hearing loss of up to -40 dB produced by otitis media (OM)[4]. Shield & Dockrell (2009) found that there are, at any time, 40% of students with some form of hearing impairment in a classroom in the United Kingdom, either permanent or temporary due to colds and other illnesses.

[4] Middle ear infection

Aside from the hearing impaired subgroup, the English as a Second Language (ESL) subgroup of children, is of special consideration. For the same reasons that children need better acoustic conditions to fully understand speech than adults, second language learners at any age have a greater need than native English learners (Nelson et al., 2005) for a higher SNL and lower background noise levels. The limited previous knowledge of the language results in a decreased ability to “fill in the blanks”, handicapping the understanding of speech.

According to the 2000 U.S. Census, 10% of individuals counted were not born in this country. By 2010, it was estimated that one of every five schoolchildren would be a recent immigrant to the United States, and the majority of these children would likely have acquired languages other than English at home (U.S. Bureau of the Census, 2000).

Even though the recommendations call for a maximum background level of 35 dBA, in the United States the typical unoccupied classrooms range from 41 to 51 dB(A) (Bess et al., 1984; Crandell & Smaldino, 1994). RT’s rarely meet the recommended standard and SNR’s tend to be no higher than 5 dB (Manlove, Frank, & Vernon-Feagans, 2001).

Morgan (1917) concluded through experimental research that to overcome a disturbance such as noise takes an extra amount of energy employed in the adaptation process, and so one pays with the loss of some basic mental abilities. During his experiment subjects were asked to memorize a set of paired associations between a one-syllable word and a one-digit number under quiet and noisy conditions. The results are inconclusive as far as the effect of noise in memorizing, however, the subjects pressure on the keys was increased during the noisy periods and two days later when asked to recall the associations, the subjects would not recall as many of the words from the noisy period as from the quiet one. This led to the conclusion that even though humans have the ability to adapt to noisy conditions, there is some stress involved in the adaptation and such adaptation is only of a temporary sort, not avoiding the disturbance effect in the more permanent learning.

There are other effects of acoustic disturbance upon a person. Laird (1930) reviews a number of experimental research papers and lists results as varied as the effect of noise in the length of reaction time (Cassell & Dallenbach, 1918; Tanzi, 1891), effect of music style in speeding or slowing down activities (Shoen, 1927), effect of noise level upon immediate memory and speed of 3-digit multiplication (Laird, unpublished), effect of noise on bodily functions like breathing (Corbeille & Baldes, 1929; Skaggs, 1926), systolic blood pressure (Boas & Weiss, 1929; Landis, 1925; Patrizi, 1896), effect of sudden noises on psychological reactions (Jacobson, 1929; Watson, 1919) and finally, the effect of noise in performance (Bills, n.d.; Laird, 1927, 1928; McGuinness, n.d.).

From these results it can be concluded that it is not only the impossibility to hear a clear signal (the teacher's and other students' voices) that affects performance. Even for individual work, background noise can be a problem.

Many solutions to the problem have been tried in already built classrooms. Most of them oriented towards the methodology of teaching rather than the space design and choice of mechanical systems. This is probably due to the lack of knowledge in these aspects of noise on the part of the teacher and school directives. As a first measure teachers try to increase the SNR by increasing their voice levels, causing vocal fatigue and throat problems. A better solution is to decrease the distance between the teacher and the students, but this is not always possible in overcrowded classrooms (Manlove, Frank, & Vernon-Feagans, 2001). The control of the teacher over the student group influences the activity noise inside the classroom. When an acoustical consultant is called to advise, they usually suggest curtains and ceiling tiles as inexpensive sound absorbers to help reduce RT, and better mechanical systems to decrease noise and also increase SNR. Other solutions relating to the placement of soft (sound absorbing) materials are usually not considered due to the need for surfaces that can be easily sanitized (Manlove, Frank, & Vernon-Feagans, 2001). Most solutions, though, must come from the design phase of the classroom, that is, from the architecture and construction. An adequate site, distant from busy roads is a very good start (Siebein et al., 2000); others are low sound transmission between massive, air-tight, and structurally discontinuous walls dividing the different classrooms, and more important, the spaces devoted to sports and recreation activities, as well as gatherings and school meetings. Mechanical system design is also of great importance, considering that HVAC systems are the primary noise source in classrooms (Nelson & Soli, 2000). Mechanical noise can be reduced by the use of quieter systems and better mechanical room design.

All of the previous studies conducted in the area of classroom acoustics address the need of the teacher's voice to be fully intelligible for students, as the signal of interest in the classroom. Some of them also address the need for communication from the students towards the teacher in the form of questions or assessments of content understanding. Very few studies have considered the need for communication between children, which is the cause of incidental learning. This is critical especially for children with hearing disabilities, when left out from the questioning and opinions of classmates as an additional source of learning.

The lack of adequate school facilities not only affects children but also teachers. Absenteeism is increased due to voice problems caused by poor acoustics, visual problems caused by poor lighting, colds and respiratory diseases caused by poor indoor air quality, back and body pain caused by ergonomically poor design. Teacher performance is affected as well and this is a direct cause of decreased student performance.

2.3. The Opposite View

Many studies have given us evidence of an effect of the physical environment on student performance. During this extensive search for evidence, one study was found to claim that no effect exists at all of building condition on student performance. Picus, Marion, Calvo & Glenn (2005) begin their report with an analysis of previous research available. Valid claims on the deficiencies of other studies include the lack of control for social and demographic variables, the weaknesses of measurement tools and the inconclusiveness of data to derive conclusions from. Their own study was performed in Wyoming using an instrument of school building condition evaluation implemented by the state and a dataset of state achievement scores. The study was performed in terms of funding and this is where the weakness of the study lies. Twenty-two building subsystems were individually evaluated and an overall condition score was given for the school. This overall score was an addition of all individual subsystem scores, after economically weighing them. That is, the more expensive to bring the subsystem to a "like new" condition, the higher weighing it received. We can see how this method of weighing can produce confounding results about the effect on student performance. If the foundations of the building required repair, this would be more expensive than if the lamps needed to be changed, and studies have found evidence that structural issues have little or no influence on student performance (Picus et al, 2005), while poor lighting has a significant effect (Heschong, 2003).

There is another approach taken by Dunn (1987) where she provides evidence that the higher achievement is not necessarily related to the "ideal" classroom conditions but to student preference of style. This condition would be much harder to provide in a school setting if we consider that the preferences of every single student are different. It is important though to take from this study that teachers could look at the underachievers in their classes from a different perspective and find a way to offer them a change in the environment that might provide better comfort.

2.4. Summary

> Anyone can adapt himself to conditions so that the work in hand will show little or no effect of any ordinary disturbance or even of an extraordinary one (it is the habit of the human organism to so adapt itself) but the object of studying the effects of environmental conditions is not to find whether one can so adapt himself, it is to see by what means he does so (Morgan, 1917, p. 208).

Morgan's quote summarizes our purpose. As designers, planners and builders of school facilities we have the obligation to provide the best possible learning environment for children, with and without special needs, remembering the teachers as an important piece of that learning environment. With so many schools built under par conditions in the past 4 decades it is important to carefully analyze which parts of the physical environment are calling for an improvement. Even mobile and temporary classrooms can be designed to provide a good learning environment if intelligent strategies are used.

CHAPTER 3. LINKING HEATING VENTILATION AND AIR CONDITIONING (HVAC) SYSTEMS AND STUDENT ACHIEVEMENT IN ELEMENTARY SCHOOLS

Ana M. Jaramillo[5]
Michael Ermann
Patrick Miller

ABSTRACT

This line of inquiry links building mechanical system type to student achievement: the noisiest types of equipment were found to cool the schools with lower test scores. In schoolrooms, particularly those in warm climates, the air-conditioning system is by far the largest contributor to (unoccupied) room noise [Bradley, 2002; Nelson et al., 2005; Siebein et al., 2000]. Yet some cooling system types, by the proximity of their fans and compressors, clatter more than others. Young students exposed to noise suffer losses of concentration, cognition, and the content of the class conveyed through oral communication. The problem is worse still for non-native speakers, those sitting adjacent to the noise source, and those who suffer head colds, ear infections, and permanent hearing loss. An examination of 73 elementary schools in a single Orlando, Florida school district suggests that, for schools populated with students of similar socio-economic background, those cooling with the noisiest types of mechanical system underperformed on achievement tests relative to those utilizing quieter types of systems. Additionally, schools at the lower end of the socio-economic continuum were found more likely to utilize noisy types of cooling systems.

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[5] E-mail: anaja@vt.edu

I. INTRODUCTION

A. Mechanical noise in classrooms

Researchers have established HVAC noise as the most significant source of classroom noise[1-2] and the type of cooling system usually controls the level of overall mechanical noise[1]. In almost all cases, air conditioning systems have two noisy components: a compressor that makes cool air in the refrigeration machine, and a fan that delivers it by moving the air over a cold coil (itself cooled by the refrigeration machine) for delivery into a conditioned space[6]. Air conditioning noise in empty classrooms with mechanical systems operating, range from NC-27 to greater than NC-65. For reference, typical classroom background noise design recommendations call for *maximum* levels of near NC-30[2-8]. It is therefore commonplace for mechanical systems alone to exceed design background noise recommendations.

Within this framework of noisy compressors and noisy fans serving (ostensibly) quiet classrooms, there exists a wide range of mechanical system noise levels—some systems are sufficiently quiet, but many systems are far too noisy. Much of the variance, perhaps most of it, can be attributed to the proximity of the compressor and the fan to the classroom. This is because some cooling systems types are characterized by distant noisy components, perhaps 75 meters from classroom occupants in remote mechanical rooms, while others are characterized by noisy components only one meter from students' ears. For purposes here, mechanical noise cooling systems are divided into three classifications: (1) remote fan and compressor, (2) fan in room, and (3) fan and compressor in room.

Systems with a remote fan and compressor make the least noise (measured at NC-27 to NC-45, speech intelligibility is rated as "good to excellent," and RASTI values are 0.55 to 0.75). Termed "central" systems, they feature refrigeration machines, and the

[6] Search "professorermann" on You Tube for animations describing how air conditioning works.

compressors that operate them, in dedicated mechanical rooms, outside the building, or in a separate building altogether. These machines then provide chilled water or cold refrigerant to the fans in mechanical room air-handling units (AHUs). In this regime, the mechanical room fans supply air, *via ductwork*, to the individual classrooms. Besides their noise advantage, these systems require fewer pieces of equipment to purchase and maintain, and provide more energy-efficient operation.

The second type, systems with a local fan and remote compressor, make more noise (measured at NC-40 to NC-47, speech intelligibility rated “good to very good,” and RASTI values are 0.50 to 0.65). Called “fan coil units,” they operate by supplying chilled water or cold refrigerant to fans located in, or just adjacent to, the space they serve. In this way, the refrigeration machine, with its noisy compressor, is far away, but the fan coil unit (FCU) with its noisy fan is nearby. The FCUs may be located in a closet adjacent to the classroom, in the ceiling of the classroom, or within the classroom itself. This model allows for good individual zone thermal control, avoids the space and cost requirements of ductwork, and in older buildings, provides for less-disruptive renovations, because the pipes that bring the chilled water to each room are smaller and therefore simpler than ducts to shoehorn in.

The third type, systems with a local fan and local compressor make, in aggregate, the most noise (measured at NC-45 to NC-65+, speech intelligibility rated “bad, poor, fair, or good,” and RASTI values are 0.10 to 0.50). Coined “through-the-wall units,” “unitary units,” “direct expansion (DX) units,” or “window units,” they feature both the noisy fan and noisy compressor in one appliance. And that one appliance is located in a wall or window of the classroom, with portions both inside and outside of the building enclosure. Through-the-wall systems offer good thermal control, require neither piping nor ductwork, and are also expedient when designing renovations to older buildings[1].

Table 1. HVAC type categories

	Remote fan and compressor	Fan in room	Fan and compressor in room
Description	Neither fan nor compressor are exposed to the classroom	Fans are exposed to the classroom but compressors are not	Both fans and compressors are exposed to the classroom
Examples	Central. Remote chillers with central AHUs. Rooftop units are not included.	Remote chillers with local fan coil units in the classrooms themselves, fan coil units above the classroom ceilings, or fan coil units in classroom closets	Self-contained DX, unitary, through-the-wall, or window units

The local fan and local compressor systems are not only noisier than their more centralized cousins, they are also *enough* noisier to often obscure the speech of the teacher. The impact of increasing mechanical noise associated with increasingly noisy mechanical systems is minimal, provided the speech signal maintains at least a 20-decibel advantage over the background noise. However the relationship shifts abruptly as the noise level approaches and then exceeds the signal—exactly the situation found with noisier window units[9-11].

B. Noise and performance in children

Studies suggest that the physical classroom environment—views, lighting, daylighting, air quality, overcrowding, thermal comfort, and furnishings—meaningfully impact student performance[12-16]. Specific to acoustics, at least 13 studies over 34 years have linked the aural environment to student cognition, concentration, and achievement (as well as teacher fatigue)[11,17-28]. Young brains do not properly "fill-in-the-gaps" when they've missed a word in a sentence, leaving them deprived of the meaning of the sentence and absent ownership of school content[2,7]. And while poor room acoustics is a common problem in classrooms, it is background noise that typically deviates farther from the ideal[29]. The effect is most pronounced on the youngest students, non-native language speakers, and those with hearing difficulty, including children with colds and ear infections.

In their study Crandell and Smaldino[7] found that children with hearing impairment performed poorer than children with normal hearing under most listening conditions, however, performance decreased significantly for the hearing impaired group when listening conditions worsened. Furthermore, the addition of a hearing aid did not improve perception in the hearing impaired group. This finding held for minimal degrees of hearing impairment as well. Others have reported similar findings[10].

Children learning in a second language also require better acoustic conditions to fully understand the spoken language[2]. Bilingual children are affected more by the presence of background noise due to their lack of language experience, thus a decreased ability to "fill in the blanks". In the United States, English-as-second-language is a growth group: 20% of school-age children are now recent immigrants and speak a language other than English at home[30].

II. METHODS

A. Characterizing school HVAC systems

Orange County, Florida includes Orlando and is one of the largest school districts in the U.S., providing a sizeable sample. Out of the 129 elementary schools in the district, 73 answered an HVAC survey given to facility managers (56% response rate) to determine cooling system type. The warm southern US climate necessitates air conditioning almost year-round, so heating systems—which may be of a different type and noise level than cooling systems—do not confound the data. Studying aggregate data (school level mechanical system types, school level achievement test scores) allows analysis independent of the daily weather variations that affect cooling loads, and allows analysis independent of the daily peculiarities that affect student performances (i.e. last day of school before a long school break, school assembly replaced recess, etc.). Others have measured noise levels at classroom resolution with and without students[25, 31-37].

B. Measuring student achievement

The Florida Comprehensive Assessment Test (FCAT) is the state-wide achievement test used for this study. Standardized test scores, though limited in their assessment of absolute learning, are a proven tool to *compare* composite achievement between schools or districts[38]. FCAT scores—whole-school data—were obtained from online public records. Eight years of third grade reading and math school-level test performance data were collected, from 2003 to 2010. FCAT reports divide achievement into five quintiles, and this study used the "percentage of students in a given school scoring in the top quintile" as the variable to represent achievement.

C. Other factors

Widely known and extensively researched, a child's socio-economic status strongly predicts the average level of student achievement[39-41]. This variable, in turn often influenced by other factors such as parents' level of education and income, negatively correlates with student achievement. To quantify the composite socio-economic variable at school-level resolution it is commonplace to use the percentage of children in that school receiving free or reduced-price lunch[42-43]. This information is collected by the State of Florida and publicly available. The socio-economic variable is so much more influential than all others, it is necessary to first filter for it when seeking the effect of HVAC system types—and mechanical noise—on student achievement. Schools' gender balances, minority enrollment rates, percentages of non-native speakers, ages of schools, and class sizes were also tabulated and statistically analyzed against student achievement.

A follow-up email survey was distributed to 396 third grade teachers in the district, garnering 87 responses (22% response rate). Teachers were asked if their classroom is noisy, what the loudest source of noise in the classroom is, if they adjust teaching strategies to overcome noise, how important they consider classroom background noise, and whether they feel background noise affects learning.

While teacher quality has been widely demonstrated to impact test scores[44-45], high-quality teachers have been shown to be randomized across schools within a district[44]. Teacher quality is therefore assumed to be sufficiently randomized in this Orange County, Florida district. Further, in her landmark study linking classroom daylighting and student test scores, Lisa Heschong[13] found that neither a teacher's education level nor a teacher's years-of-experience[5,43] were correlated to "better daylit" classrooms. For acoustics, the present inquiry assumes that these findings hold for quieter classrooms as well, and that certain kinds of teachers are not more or less likely to occupy noisy classrooms[44].

The 73 schools that responded to the HVAC survey were mapped to tease out geographic patterns indicative of confounding variables and spurious relationships. No such patterns were evident. Mapping software also allowed for removal from the data set of those schools found having rooftop package units (4 removed). Rooftop units, even though technically belonging to the quietest type of mechanical system (central system with fan and compressor remote), often create high levels of noise through vibration, poor ceiling isolation, and insufficient duct length between the AHU fan and the classroom it serves below.

Mapping also identified subsets of schools in proximity to major roads (15 schools) and airports (19 schools), but the follow-up survey of teachers in the district suggested that road and aircraft noise was of negligible impact, so the schools near highways and airports remained in the dataset. Discussions with district staff were combined with survey results to identify one school with partial-height partitions separating classrooms. Such configurations offer inadequate acoustic separation and speech privacy between classrooms, potentially clouding data that might illuminate the effect of mechanical system noise. That one school was also removed from the data set.

D. Statistical analysis methods

Multiple regression analysis was used for this study. After the initial search for patterns multiple models were created to understand the possible effect of all collected variables and those variables eliminated were done so through a stepwise process.

III. DATA

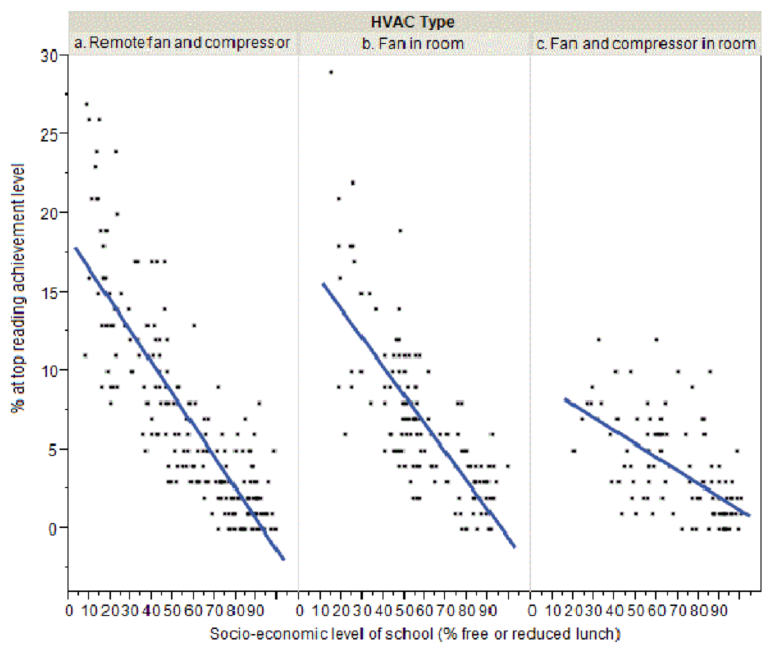

Figure 1. Reading achievement by socio-economic status per HVAC type.

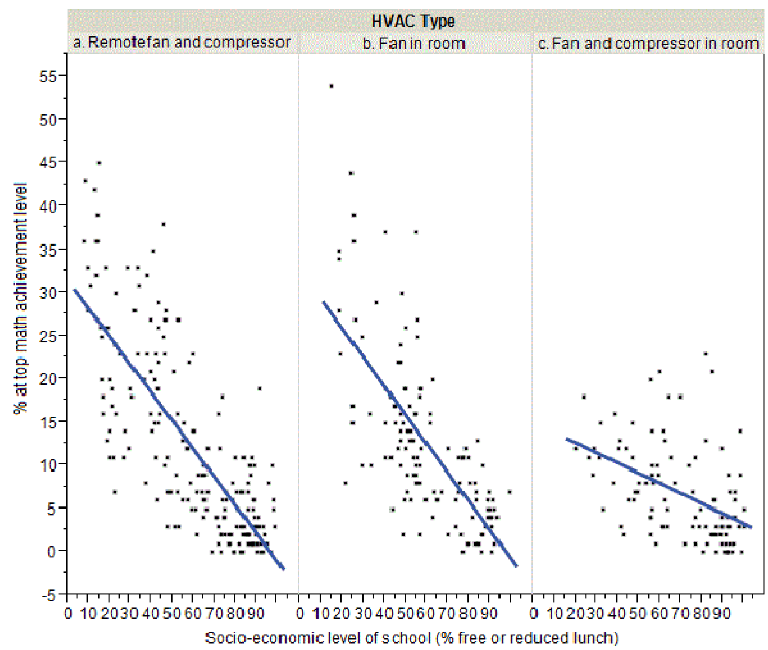

Figure 2.. Math achievement by socio-economic status per HVAC type.

Each point in Figures 1 and 2 scatterplots represents the percentage of a given school's pupils scoring in the top quintile of a third grade student achievement test for a given year. Eight years' worth of data are recorded (when available), so there are eight dots per school. The schools' composite achievement test data is plotted against the socio-economic status of the students in that school, as measured by the percentage of students receiving free and reduced-price lunch. The data are further culled into three categories corresponding to the types of mechanical systems present in the schools from quietest type (Remote fan and compressor) on the left to noisiest type (Fan and compressor in room) on the right.

Examining the data graphically, two trends emerge. First, the schools with low numbers of students receiving free or reduced price school lunch, "richer schools," outperform those with high numbers of students receiving school lunch, "poorer schools." The socio-economic variable in the model was found to be responsible for about 50% of the variance in test scores (R^2=0.56 for reading and R^2=0.48 for math), and the chances of that correlation being random was found to be less than 5 percent ($p<0.05$). Second, after accounting for the socio-economic variable, schools with the noisiest systems, through-the-wall equipment with both the fan and compressor exposed to the room, underperform on the achievement tests relative to the schools that cool with quieter central systems or fan coil units. The cooling system type variable in the model was found to be responsible for 10% of the variance in test scores ($R^2=0.66$ for reading and $R^2=0.57$ for math), and the chances of that correlation being random was found to be less than 5 percent ($p<0.05$).

A third, less graphically obvious, but statistically significant, finding: Richer schools are more likely to have quiet systems and poorer schools are more likely to have noisy systems, so there are proportionally more data points on the high end of the socio-economic spectrum for central systems and on the low end of the socio-economic spectrum for through-the-wall systems ($p<0.05$). Perhaps richer schools have the clout or wherewithal to ensure a quiet cooling system serves their classrooms. One might also propose that poorer residents live in older neighborhoods where older schools that added air conditioners sidestepped the retrofit difficulties associated with running ductwork through existing partitions and floors (see Figure 3). However, for the schools in this study, the age of the school was found insufficiently related to the socio-economic rank ($p>0.05$).

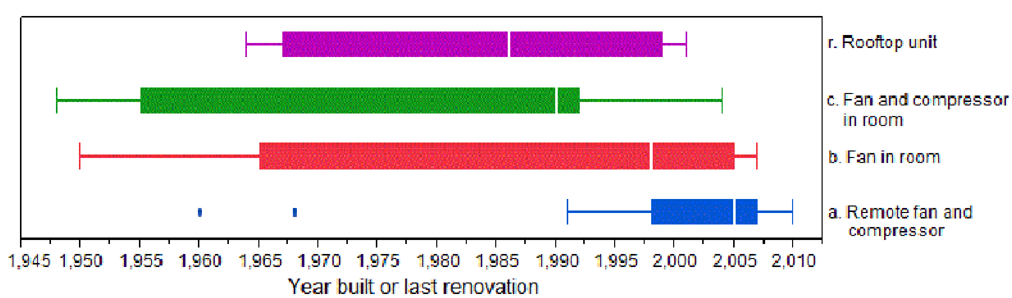

Figure 3. HVAC type by age of school built or last renovated.

Table 2. Multiple regression values for model predicting reading achievement from socio-economic level

RSquare	0.56
RSquare Adj	0.56
Root Mean Square Error	3.59
Mean of Response	5.93
Observations (or Sum Wgts)	982

Table 3. Analysis of variance of previous model.

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	16007.52	16007.50	1239.63
Error	980	12654.91	12.90	**Prob > F**
C. Total	981	28662.43		<.0001*

Table 4. Parameter estimates of previous model

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	15.71	0.30	52.29	<.0001*
% Free or Reduced Lunch	-0.16	0.00	-35.21	<.0001*

Table 5. Multiple regression values for model predicting math achievement from socio-economic level

RSquare	0.48
RSquare Adj	0.48
Root Mean Square Error	7.06
Mean of Response	10.73
Observations (or Sum Wgts)	982

Table 6. Analysis of variance of previous model.

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	44757.66	44757.70	898.74
Error	980	48804.44	49.80	**Prob > F**
C. Total	981	93562.10		<.0001*

Table 7. Parameter estimates of previous model

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	27.08	0.59	45.90	<.0001*
% Free or Reduced Lunch	-0.27	0.01	-29.98	<.0001*

Table 8. Multiple regression values for model predicting reading achievement from socio-economic level, HVAC type and the interaction of both.

RSquare	0.67
RSquare Adj	0.66
Root Mean Square Error	3.12
Mean of Response	6.00
Observations (or Sum Wgts)	434

Table 9. Analysis of variance of previous model.

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	8360.357	2786.79	285.47
Error	430	4197.634	9.76	**Prob > F**
C. Total	433	12557.991		<.0001*

Table 10. Parameter estimates of previous model

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	13.87	0.568	24.43	<.0001*
HVAC Type (c-a&b)	-0.92	0.186	-4.94	<.0001*
% Free or Reduced Lunch	-0.14	0.008	-17.55	<.0001*
HVAC Type (c-a&b)*(% Free or Reduced Lunch-61.7736)	0.05	0.008	6.95	<.0001*

Table 11. Effect tests of previous model

Source	**Nparm**	**DF**	**Sum of Squares**	**F Ratio**	**Prob > F**
HVAC Type (c-a&b)	1	1	237.99	24.38	<.0001*
% Free or Reduced Lunch	1	1	3007.01	308.03	<.0001*
HVAC Type (c-a&b)*% Free or Reduced Lunch	1	1	471.04	48.25	<.0001*

Table 12. Multiple regression values for model predicting math achievement from socio-economic level, HVAC type and the interaction of both.

RSquare	0.57
RSquare Adj	0.57
Root Mean Square Error	6.48
Mean of Response	11.05
Observations (or Sum Wgts)	434

Table 13. Analysis of variance of previous model.

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	3	24064.50	8021.50	191.07
Error	430	18052.38	41.98	**Prob > F**
C. Total	433	42116.89		<.0001*

Table 14. Parameter estimates of previous model

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	23.39	1.18	19.87	<.0001*
% Free or Reduced Lunch	-0.22	0.02	-13.58	<.0001*
HVAC Type(c-a&b)	-1.89	0.39	-4.90	<.0001*
(% Free or Reduced Lunch-61.7736)*HVAC Type(c-a&b)	0.11	0.02	6.44	<.0001*

Table 15. Effect tests of previous model

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
% Free or Reduced Lunch	1	1	7737.09	184.29	<.0001*
HVAC Type(c-a&b)	1	1	1006.50	23.97	<.0001*
% Free or Reduced Lunch*HVAC Type (c-a&b)	1	1	1738.80	41.42	<.0001*

IV. ANALYSIS

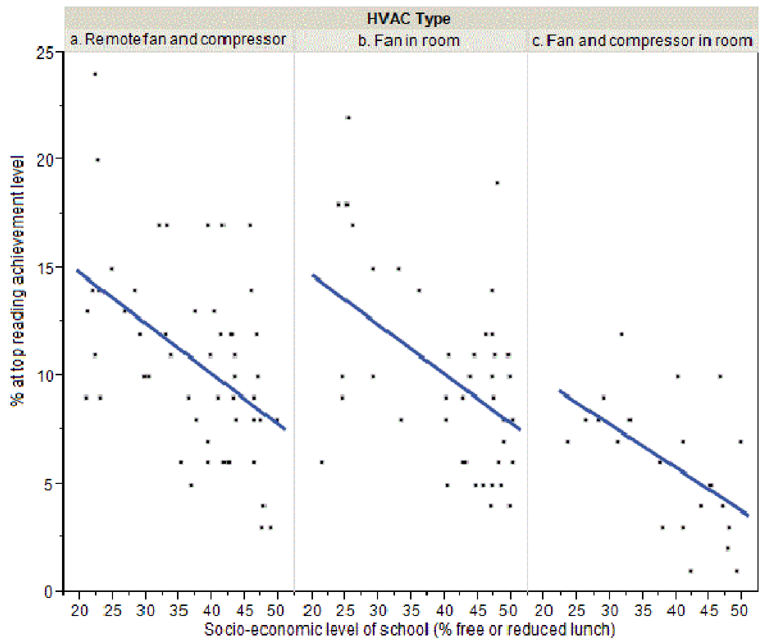

Figure 4. Reading achievement by socio-economic status per HVAC type.

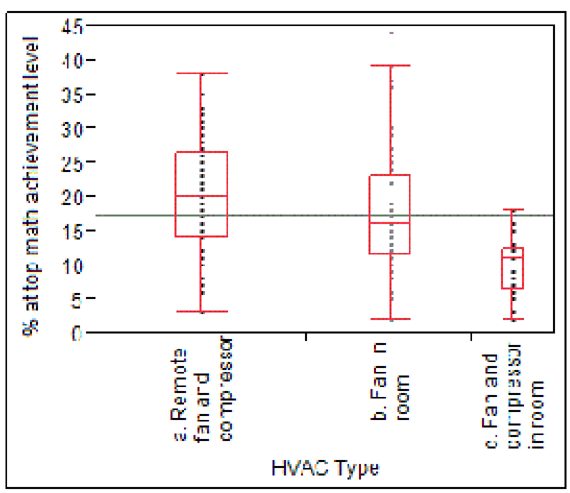

Figure 5. Math achievement by HVAC type.

While quiet systems more likely serve the rich schools and noisy systems more likely serve the poor schools in the survey, for those in the middle of the socio-economic continuum, mechanical system type and socio-economic status are sufficiently orthogonal. Figures 4 and 5 eliminate the schools on either end, culling those schools where the rates of free and reduced lunches sit between 20% and 50%. Relative to the full data set, the findings remain fairly consistent. Rich schools do better on achievement tests, *but for a given socio-economic condition, schools with the quietest types of system boast more students in the top achievement test quintile than those with noisier systems.* This is the core finding of this study. No school with both fan and compressor in the classroom has more than 12% of students at the highest level of reading achievement. A meaningful number (22%) was found for the other two quieter cooling regimes. The mechanical system type variable in this truncated model was found to be responsible for 17% of the variance in test scores (R^2=0.17), and the chances of that correlation being random was found to be less than 5 percent ($p<0.05$). It should be noted that for this partial window, between 20% and 50% receiving free lunch, the effect of socio-economic rank on test scores is diluted for reading (R^2=0.21) and absent for math (R^2=0.04). When including the entire socio-economic spectrum, the correlation is strong for both (see Tables 2 and 5).

The other school-wide variables studied proved less predictive of student achievement than mechanical system type and socio-economic status. Schools' minority rates demonstrated dependence on socio-economic status (Spearman's correlation = 0.59), so socio-economic status was selected because it was more predictive of test scores (R^2=0.57 vs. R^2=0.45). Schools' gender balance revealed no significance ($p>0.05$) in early models and was removed from the analysis. The percentage of non-native speakers attending a school was also found to be not significantly related to student achievement ($p>0.05$), however, there is a relationship between non-native speakers and achievement when considering noise level (see Figure 6). Finally, a school's average class size was not significantly different among schools to be of statistical significance ($p>0.05$).

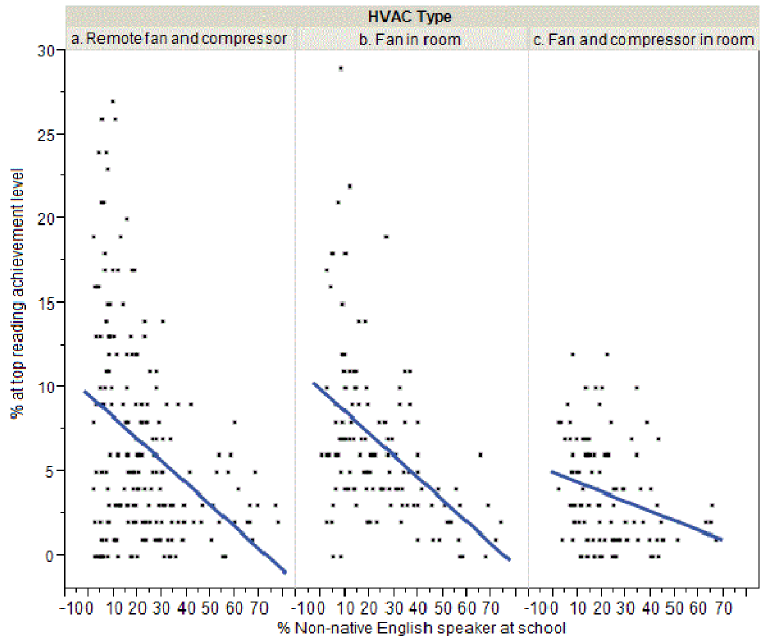

Figure 6. Reading achievement by percentage of non-native speakers at school per HVAC type.

Table 16. Multiple regression values for model predicting reading achievement from HVAC type.

Rsquare	0.16
Adj Rsquare	0.14
Root Mean Square Error	4.18
Mean of Response	9.62
Observations (or Sum Wgts)	115

Table 17. Analysis of variance of previous model.

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**	**Prob > F**
HVAC Type	2	362.20	181.10	10.38	<.0001*
Error	112	1954.97	17.46		
C. Total	114	2317.17			

Table 18. Multiple regression values for model predicting math achievement from HVAC type.

Rsquare	0.17
Adj Rsquare	0.16
Root Mean Square Error	8.19
Mean of Response	17.42
Observations (or Sum Wgts)	115

Table 19. Analysis of variance of previous model.

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
HVAC Type with Rooftop	2	1553.59	776.79	11.59	<.0001*
Error	112	7506.38	67.02		
C. Total	114	9059.97			

Table 20. Mean comparison test for distribution of reading achievement among HVAC types. Levels not connected by same letter are significantly different.

Level			Mean
c. Fan and compressor in room	A		70.34
b. Fan in room		B	59.10
a. Remote fan and compressor		B	58.89

Table 21. Mean comparison test for distribution of reading achievement among HVAC types. Ordered Differences Report

Level	- Level	Diff.	Std Err Dif	p-Value
c. Fan and compressor in room	a. Remote fan and compressor	11.45	2.86	<.0001*
c. Fan and compressor in room	b. Fan in room	11.24	3.14	0.0004*
b. Fan in room	a. Remote fan and compressor	0.21	2.68	0.9391

V. DISCUSSION

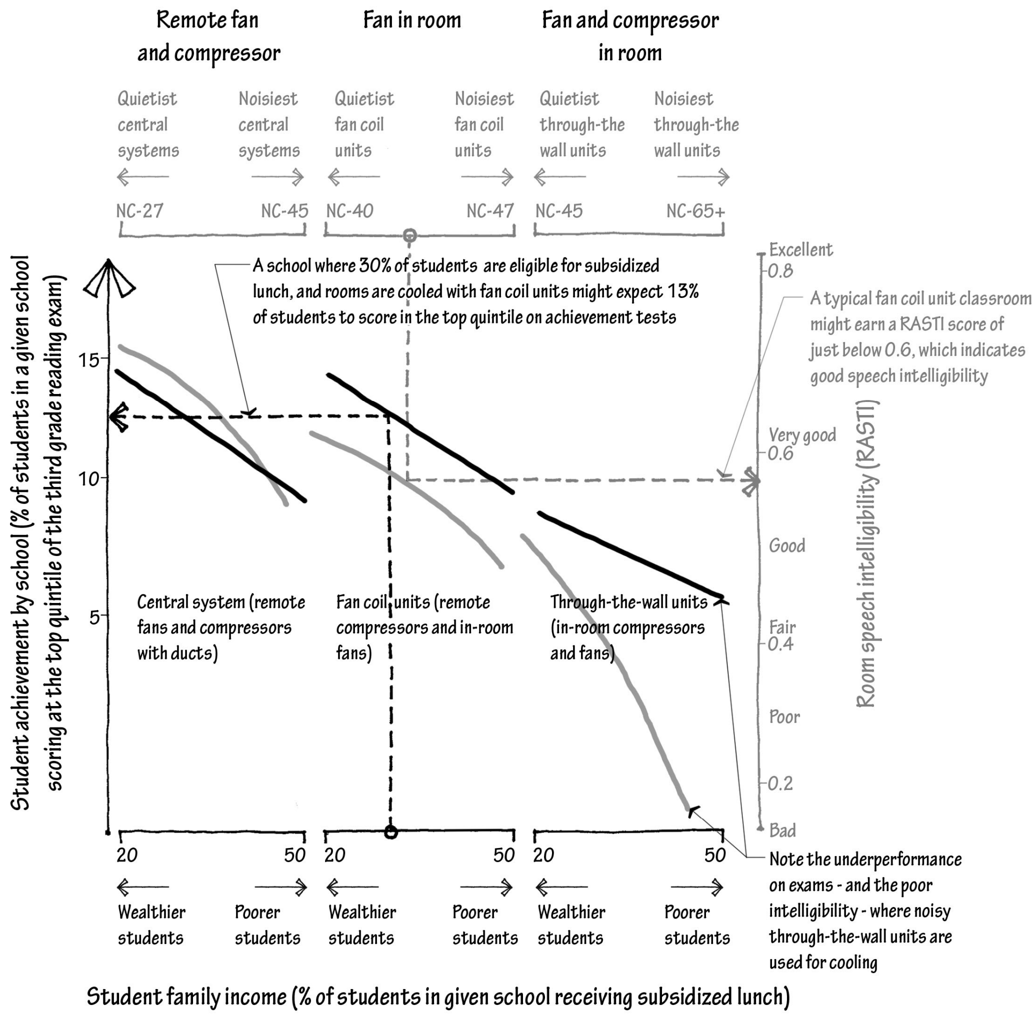

Figure 7. Student achievement by socio-economic status and mechanical system type (in black). Speech intelligibility by Noise Criteria and mechanical system type (in gray).

The theory suggests that the presence of both a fan and compressor in a room elevates background noise to a level where speech is obscured, and that the impact of increasing background noise to levels approximating through-the-wall cooling systems is non-linear—rising noise levels have modest effect on speech intelligibility until they approach the signal's level, at which time the impact is substantial. The literature further suggests that children exposed to noise encounter difficulties with concentration, cognition, and speech intelligibility. The data from these 73 schools track closely with the theory. Figure 7 suggests a parallel when comparing (1) the effects of mechanical type on speech intelligibility from a previous study[1] and (2) the effects of mechanical type on student achievement presented here.

VI. CONCLUSION

The type of mechanical system chosen for a school impacts the noise level because some systems are much louder than others; the noise level, in turn, impacts the speech intelligibility, cognition, and concentration of the students. Comparing schools' cooling system types to schools' standardized test scores suggests that the effects of mechanical noise demonstrably impact student achievement. Architects, mechanical engineers, acousticians, school boards and school district facilities personnel might therefore eschew through-the-wall air conditioners and other "fan and compressor in room" system types, and noisier heating systems like through-the-wall heat pumps, because they expose the classroom to both fan noise and compressor noise. Indeed, some of the other school districts contacted as part of this study shared their view that systems with local fan and compressor were design choices of the past, and that as a matter of policy, new schools in their district are designed with quieter, central, ducted systems.

Of particular interest for public policy, schools in this study with high proportions of students receiving free or reduced school lunch also proved more likely to utilize fan and compressor in room air conditioners—the noisiest type. This deserves more research, because the reasons for this trend are unclear. Also deserving more analysis, the 87 third grade teachers surveyed were generally unconcerned with noise, and when they expressed concern, it generally was directed at the kind of distracting noise associated with speech privacy, like kids talking in the halls during lesson times. When prompted, the teachers generally dismissed mechanical noise as either not present or not sufficiently disruptive to address. Perhaps the acoustician's concern for mechanical noise is not borne out in the everyday experience of the classroom, or perhaps adults speaking across the room are not as affected by the noise at the child-listener, like the man in the bedroom speaking to his spouse in the shower, perplexed why she can't hear him (after all, he can hear her perfectly).

Those looking to replicate this study might account for the proportion of instructions occurring in portable classrooms, which almost always use noisy through-the-wall air conditioners, and are common in Florida schools. This study might make a case against the use of portable classrooms altogether based on expected drops in student performance in those noisy environments. Finally, as passive chilled beam technology and radiant cooling technology become more commonplace, researchers might account for this type of system, which promises to be quieter than even the quietest central systems. Some classrooms, of course, use no air-conditioning altogether, but those typically require open windows and introduce environmental noise, from outside the school.

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REFERENCES

1. G. Siebein, M.A. Gold, M. Ermann. "Ten ways to provide a high-quality acoustical environment in schools". Language, Speech, and Hearing Services in Schools, 31, 376-384 (2000).

2. P. Nelson, K. Kohnert, S. Sabur and D. Shaw. “Classroom noise and children learning through a second language: Double jeopardy?” Language, Speech, and Hearing Services in Schools, 36, 219–229 (2005).
3. H. Bess, J. S. Sinclair and D. Riggs. “Group amplification in schools for the hearing impaired”. Ear and Hearing, 5, 138–144 (1984).
4. C. C. Crandell and J. J. Smaldino. “An update of classroom acoustics for children with hearing impairment”. The Volta Review, 96, 291–306 (1994).
5. American National Standards Institute. “Standard 12.60-2002 (R2009): Acoustical performance criteria, design requirements, and guidelines for schools” (2002).
6. P. B. Nelson. “Improving acoustics in American schools”. Language, Speech, and Hearing Services in Schools, 31, 354-355 (2000).
7. C. C. Crandell and J. J. Smaldino. “Classroom acoustics for children with normal hearing and with hearing impairment”. Language, Speech, and Hearing Services in Schools, 31, 362 – 370 (2000).
8. J. S. Bradley. “Uniform derivation of optimum conditions for speech in rooms”. National Research Council of Canada. BRN 239 (1985).
9. J. S. Bradley. “Speech intelligibility studies in classrooms”. J. Acoust. Soc. Am., 80(3), 846–854 (1986).
10. M. Hodgson. “Experimental investigation of the acoustical characteristics of university classrooms”. J. Acoust. Soc. Am., 106 (4), 1810–1819 (1999).
11. P. B. Nelson and S. Soli. “Acoustical barriers to learning: Children at risk in every classroom”. Language, Speech, and Hearing Services in Schools, 31, 356-361 (2000).
12. G. I. Earthman. “School facility conditions and student academic achievement”. Los Angeles, CA: UCLA’s Institute for Democracy, Education, & Access (IDEA) (2002).
13. L. Heschong. “Daylighting in schools: An investigation into the relationship between daylight and human performance”. Pacific Gas and Electric Company (1999).

14. L. Heschong. “Window and classrooms: A study of student performance and the indoor environment”. Integrated Energy Systems, California Energy Commission (2003).
15. S. Higgins, E. Hall, K. Wall, P. Woolner and C. McCaughey. “The impact of school environments: A literature review”. London: The Design Council (2005).
16. K. Jacobs. “House bill # 443: An act relative to the consideration of ergonomically designed school buildings”. General Court of Massachusetts public hearing (October 6, 2009)
17. A. L. Bronzaft and D. P. McCarthy. “The effect of elevated train noise on reading ability”. Environment and Behavior, 7 (4), 517-528 (1975).
18. J. E. Dockrell and B. M. Shield. “Acoustical barriers in classrooms: The impact of noise on performance in the classroom”. British Educational Research Journal, 32, 509–525 (2006).
19. S. Hygge, G. W Evans and M. Bullinger. “A prospective study of some effects of aircraft noise on cognitive performance in schoolchildren”. Psychological Science, 13 (5), 469-474 (2002).
20. A. M. Jaramillo and M. G. Ermann. “Linking HVAC type noise and student achievement”. InterNoise and NoiseCON Conference Proceedings, New York City NY, 3973-4937 (2012).
21. Maroko and Shwe, Inc. and Schaffer Acoustics Inc. “HVAC systems acoustical, cost & energy study for the Los Angeles Unified School District” (2005).
22. L. M. Ronsse and L. M. Wang. “Acoustics of elementary school classrooms: Correlations of varying background noise level and reverberation time to student achievement”. InterNoise Conference Proceedings. Ottawa, Canada (2009).
23. B. M. Shield and J. E. Dockrell. “The effects of environmental and classroom noise on the academic attainments of primary school children”. J. Acoust. Soc. Am., 123 (1), 133-144 (2007).
24. G. W. Siebein and R. M. Likendey. “Acoustical case studies. ASHRAE Journal (2004).

25. S. A. Stansfeld, B. Berglund, C. Clark, I. Lopez-Barrio, P. Fischer, E. Ohrstrom, M. M. Haines, J. Head, S. Hygge, I. van Kamp and B. F. Berry (on behalf of the RANCH study team). "Aircraft and road traffic noise and children's cognition and health: A cross-national study". Lancet, 365, 1942-1949 (2005).
26. G. Vilatarsana. "The environmental noise exposure of schools around Heathrow" (MS Thesis). South Bank University. London, UK. (2004).
27. S. S. Zentall and J. H. Shaw. "Effects of classroom noise on performance and activity of second-grade hyperactive and control children". Journal of Educational Psychology, 72 (6), 830-840 (1980).
28. A. F. Zusman. "Findings of the FICAN pilot study on the relationship between aircraft noise reduction and changes in standardized test scores". Federal Interagency Committee on Aviation Noise (2007).
29. J. S. Bradley. "Acoustic design of rooms for speech". Construction Technology Update, 51, (2002).
30. U.S. Bureau of the Census. "Languages spoken at home" (2000).
31. H.A. Knecht, P.B. Nelson, G. M. Whitelaw and L.L. Feth. "Background noise levels and reverberation times in unoccupied classrooms: Predictions and measurements". American Journal of Audiology, 11, 65-71 (2002).
32. Y. Avsar, and T. Gonullu. "The influence of indoor acoustical parameters on student perception in classrooms". Noise Control Eng. J., 58 (3), 310-318 (2010).
33. A. L. Bronzaft. "The effect of a noise abatement program on reading ability". Journal of Environmental Psychology, (1), 215 – 222 (1981).
34. C. Y. Choi and B. McPherson. "Noise levels in Hong Kong primary schools: Implications for classroom listening". International Journal of Disability, Development and Education, 52 (4), 345–360 (2005).
35. P. Lundquist, K. Holmberg and U. Landstrom. "Annoyance and effects on work from environmental noise at school". Noise and Health, 28, 39-46 (2000).
36. L. M. Ronsse and L. M. Wang. "AB-10-C037: Effects of noise from building mechanical systems on elementary school student achievement". ASHRAE Transactions, 116 (2), 347-354 (2010).

37. B. M. Shield and J. E. Dockrell. "The effects of noise on children at school: A review". Building Acoustics, 10, 97-116 (2009).
38. A. L. Duckworth, P. D. Quinn and E. Tsukayama. "What no child left behind leaves behind: The roles of IQ and self-control in predicting standardized achievement test scores and report card grades". Journal of Educational Psychology, 104 (2), 439-451 (2012)
39. P. Keaton (National Center for Education Statistics). "Numbers and types of public elementary and secondary schools from the common core of data: School year 2010–11". U.S. Department of Education. (2012).
40. L.O. Picus, S. F. Marion, N. Calvo and W. J. Glenn. "Understanding the relationship between student achievement and the quality of educational facilities: Evidence from Wyoming". Peabody Journal of Education, 80 (3), 71 – 95 (2005).
41. F. Santos and R. Gebeloffny. "Teacher quality widely diffused, ratings indicate". The New York Times (February 25, 2012).
42. R. Buddin. "Measuring teacher and school effectiveness at improving student achievement in Los Angeles elementary schools". Los Angeles Times (2011).
43. Acoustical Society of America. "Classroom acoustics" (2002).
44. F. H. Bess, J. S. Sinclair and D. Riggs. "Group amplification in schools for the hearing impaired". Ear and Hearing, 5, 138–144 (1984).

CHAPTER 4. THE TEACHERS' PERSPECTIVE ON NOISE IN THE CLASSROOM

Ana Jaramillo

Michael Ermann

Patrick Miller

I. ABSTRACT

A survey was sent to 3rd grade teachers in Orange County, FL to find out about their noise awareness and coping strategies. Results of the survey were also correlated to mechanical system type and achievement data. Preliminary analyses show very little awareness on mechanical noise by teachers but a good range of coping strategies when noise sources are present (mostly activity noise). The survey also helped to better understand the classroom environment. For example, most classrooms have a frequent use of computers or projectors and a few schools are still open-plan. These facts create new questions about noise in the classroom that need to be addressed in further studies.

II. INTRODUCTION

In the past, researchers have found that the physical environment of an educational setting can have an effect on student performance. Some of the studied variables are: views, lighting, daylighting, air quality, overcrowding, thermal comfort, and furnishings (Earthman, 2002; Heschong, 1999, 2003; Jacobs, 2009). Acoustics has been specifically linked to student performance in several studies covering areas as cognition, concentration and student achievement, as well as teacher fatigue (Bronzaft & McCarthy, 1975; Dockrell & Shield, 2006; Hygge, Evans & Bullinger, 2002; Jaramillo & Ermann, 2012; Maroko & Shwe, 2005; Nelson & Soli, 2000; Ronsse & Wang, 2009; Shield & Dockrell, 2007; Siebein & Likendey, 2004; Stansfeld et al., 2005; Vilatarsana, 2004; Zentall & Shaw, 1980; Zusman, 2007). Children are affected by noise especially at early ages and a more pronounced effect has been found as well in English-as-a-second-language speakers and hearing impaired (these include children with colds and ear infections as forms of temporary hearing loss) (Bradley, 2002; Elliot, 1982). When exposed to background noise adults have the ability to “fill-in-the-blanks” for the missing words, however, this ability requires previous knowledge of the language that children and non-native speakers have not entirely acquired yet, leaving them with an incomplete understanding of the message, at best. Room acoustics are also commonly deficient in classrooms, however, background noise generally deviates farther from the recommended levels (Bradley, 2002).

Researchers have documented mechanical heating and cooling equipment noise as the prime contributor to classroom noise, (Siebein et al., 2000; Nelson et al., 2005) and the type of cooling system determines, in large part, the level of the mechanical noise in the classroom (in temperate and warm climates). Mechanical cooling noise sources may be categorized into one of three classifications: (1) remote fan and compressor, (2) fan in room, and (3) fan and compressor in room. Of the three types, the quietest typology involves air systems with distant, centralized, air handling units (AHUs) and remote chillers and cooling towers. Next loudest, AHUs and fan-coil units that serve only one space may feature remote chiller equipment but fans that are either located in the room being served, or just adjacent to it in a ceiling plenum, over a corridor, or in a closet. Finally, the loudest system typology, through-the-wall units, features both compressors and fans located in the rooms served. These are sometimes referred to as unitary systems, direct expansion systems, or DX systems, and are colloquially termed “window units” (Siebein et al., 2000)

The teacher survey results presented here complement a prior study by the same authors (Jaramillo & Ermann, 2012). That investigation surveyed 73 of the 129 elementary schools in Orange County, Florida school district and their mechanical systems were analyzed statistically against third grade school achievement test scores over eight years. The analysis found, not surprisingly, that test scores were overwhelmingly influenced by the socio-economic profile of the school’s students;

schools populated by higher-income children out-performed those populated by poorer children. But when the data were broken into three groups, each corresponding to a different type of mechanical system, the results revealed that, for any given student income level, achievement scores dropped in schools with the noisiest systems (Jaramillo & Ermann, 2012). What do the teachers in that school district think about noise in their classrooms?

III. METHODS

For the purpose of this study a large size district located in a warm climate was necessary, to avoid additional effects by a different type of heating system. Orlando, FL is one of the largest school districts found in the southern US. A survey about HVAC type was sent to the 129 elementary schools in the district and 73 responses were received (56% response rate). To complement this data, another survey was sent to third grade teachers in the same district to collect information about their experience with noise, coping strategies and attitudes. Out 396 surveys sent, 87 responses were collected (22% response rate)

Those schools found to have rooftop package units and those schools with recent HVAC system renovations were eliminated from the dataset. The 56% of schools that responded to the first survey were mapped to tease out patterns indicative of confounding variables and spurious relationships. No patterns were evident. Teacher quality, teacher education, teacher experience, school minority rate, gender balance, percentage of non-native speakers, and average class size were either tabulated in the data or sufficiently randomized.

The Florida Comprehensive Assessment Test (FCAT) is the state-wide achievement test used for this study. Standardized test scores, though limited in their assessment of absolute learning, are a proven tool to *compare* composite achievement between schools or districts. FCAT scores—whole-school data—were obtained from online published public records. Eight years of data were collected, from 2003 to 2010, in the third grade for all schools in the district. FCATs divide achievement into 5 levels, so this study uses the "percentage of students scoring in the top level" variable to represent achievement.

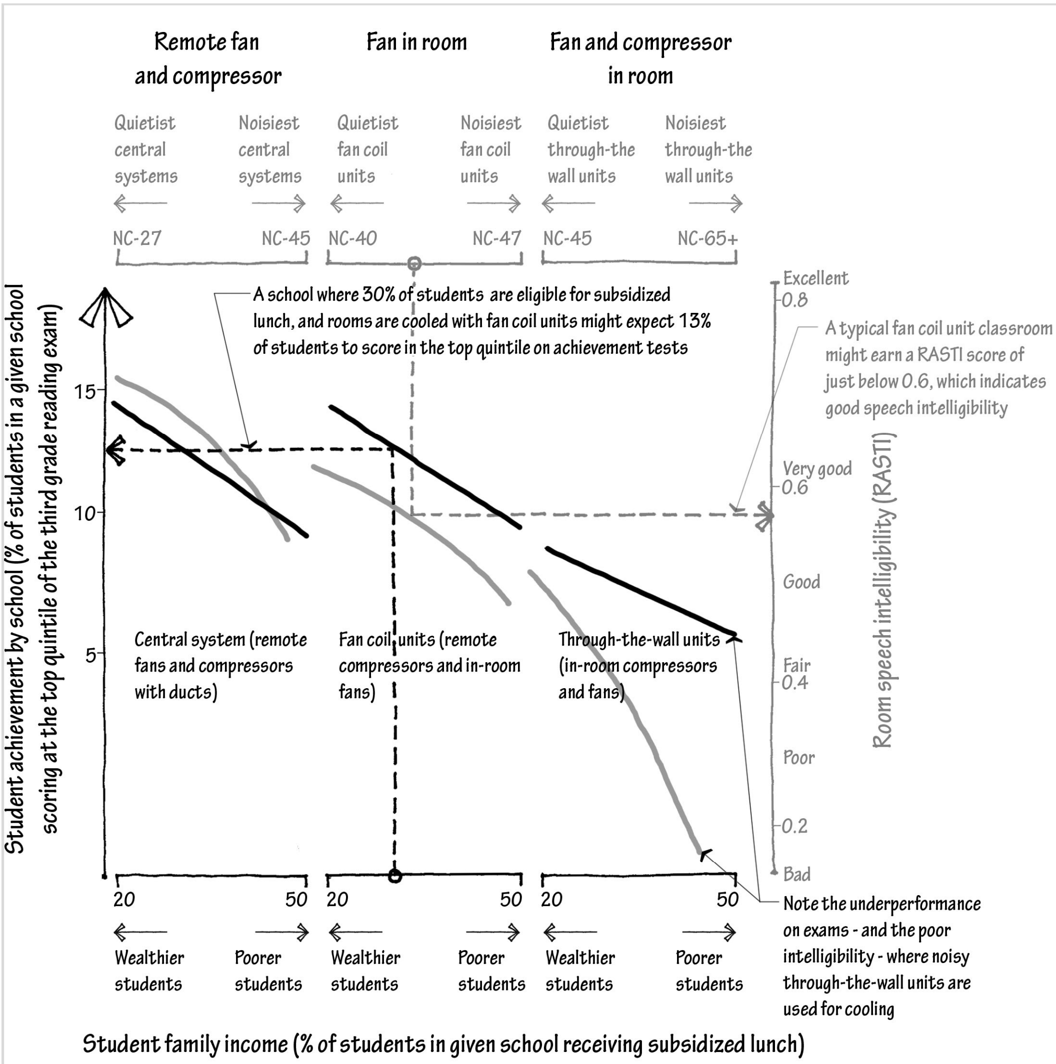


Figure 8. Student achievement by socio-economic status and mechanical system type (in black). Speech intelligibility by Noise Criteria and mechanical system type (in gray

Figure 8 overlays two studies—The antecedent for the one published here, that illustrates a sharp drop in student achievement in schools cooling with both fan and compressor exposed to the classroom (Jaramillo & Ermann, 2012), and another one that illustrates a sharp drop in speech intelligibility associated with that same type of mechanical system, the fan and compressor exposed to the classroom (Siebein et al., 2000). The empirical data tracks closely with the theory, because speech intelligibility in noisy conditions evaporates suddenly when the background levels approach, and then surpass, the speech level.

IV. DATA

1. How noisy is your classroom without students?

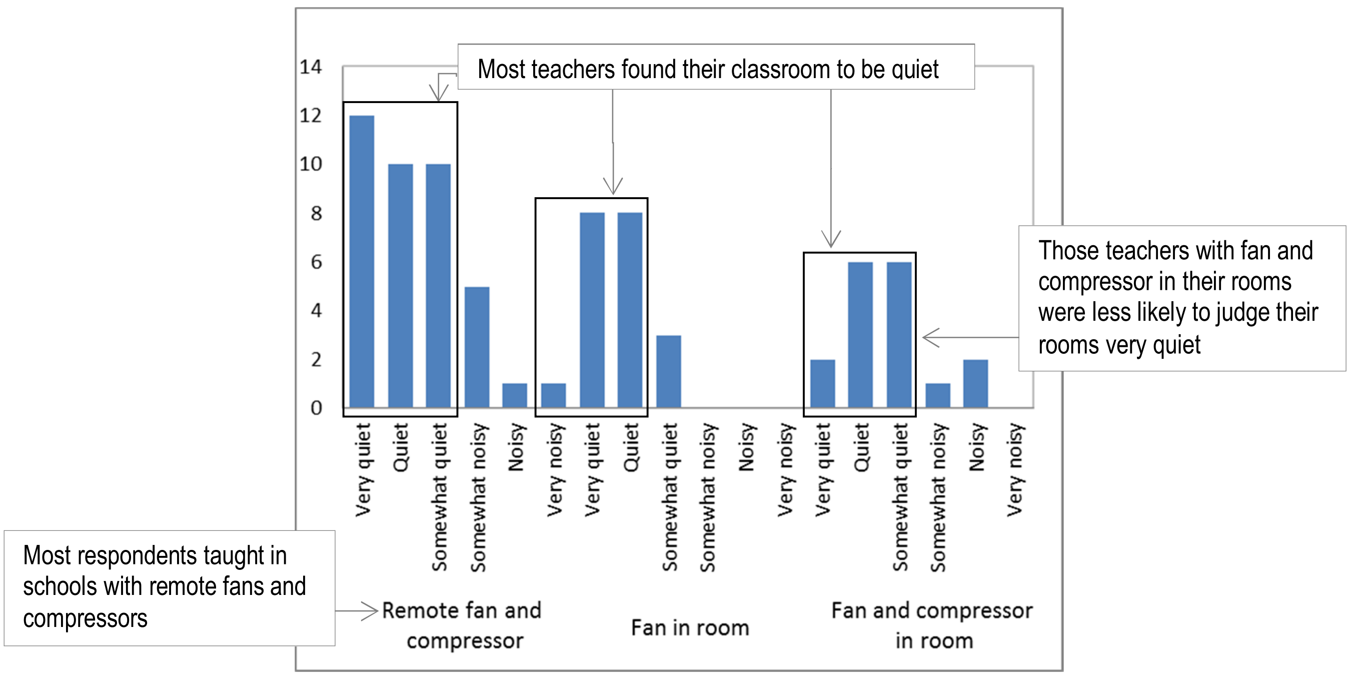


Figure 9. Perceived noisiness by HVAC type.

Table 22. Perceived noise by HVAC type, count and percentage of total responses by type.

	Very quiet		Quiet		Somewhat quiet		Somewhat noisy		Noisy		Very Noisy			
a. Remote fan and compressor	12	34%	9	26%	9	26%	5	14%	0	0%	0	0%	35	50%
b. Fan in room	7	39%	8	44%	3	17%	0	0%	0	0%	0	0%	18	26%
c. Fan and compressor in room	2	12%	6	35%	6	35%	1	6%	2	12%	0	0%	17	24%
	21	30%	23	33%	18	26%	6	9%	2	3%	0	0%		

2. How long have you been teaching at the current school?

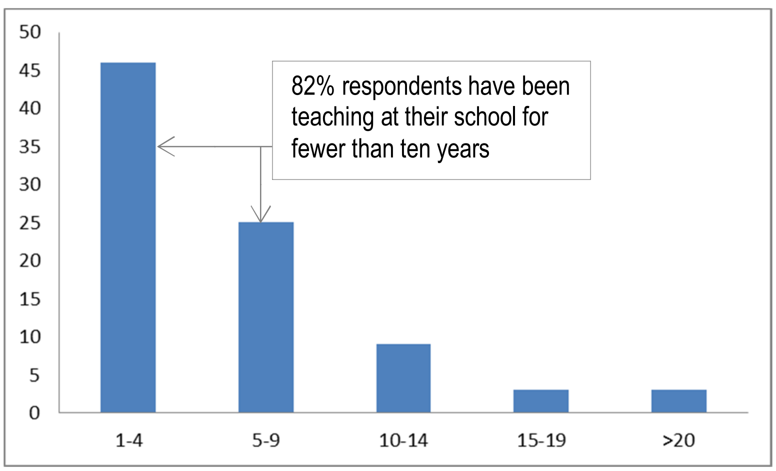


Figure 10. Years of teaching at the current school.

Though previous studies suggest adaptation should occur (Cohen, et al., 1981; Grebennikov, 2006), no significant relationship between the time spent at a particular school and noise perception was found.

3. Do you often use computers or projectors in the classroom?

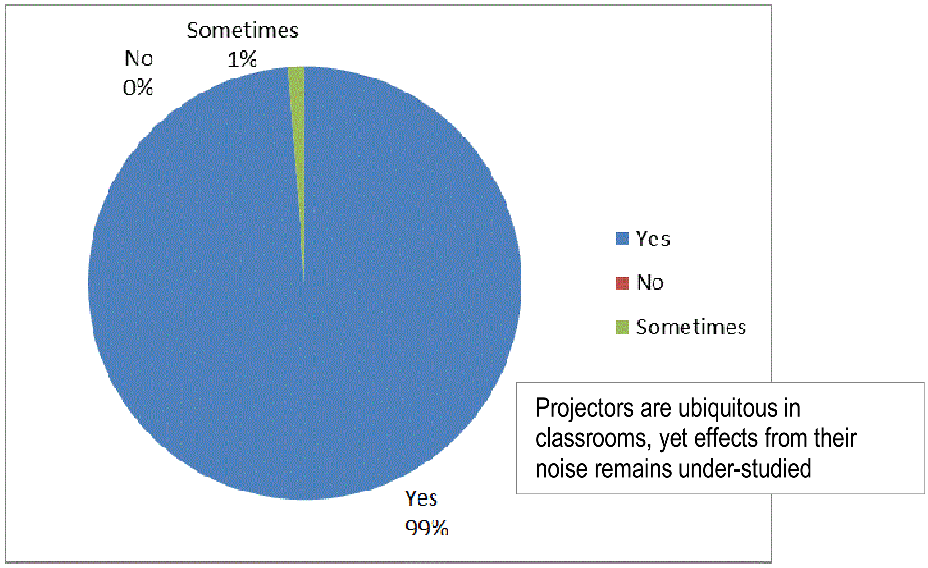


Figure 11. Percentage of teachers who use computers or projectors often in the classroom

4. Are there full floor-to-ceiling walls separating your classroom from adjacent rooms?

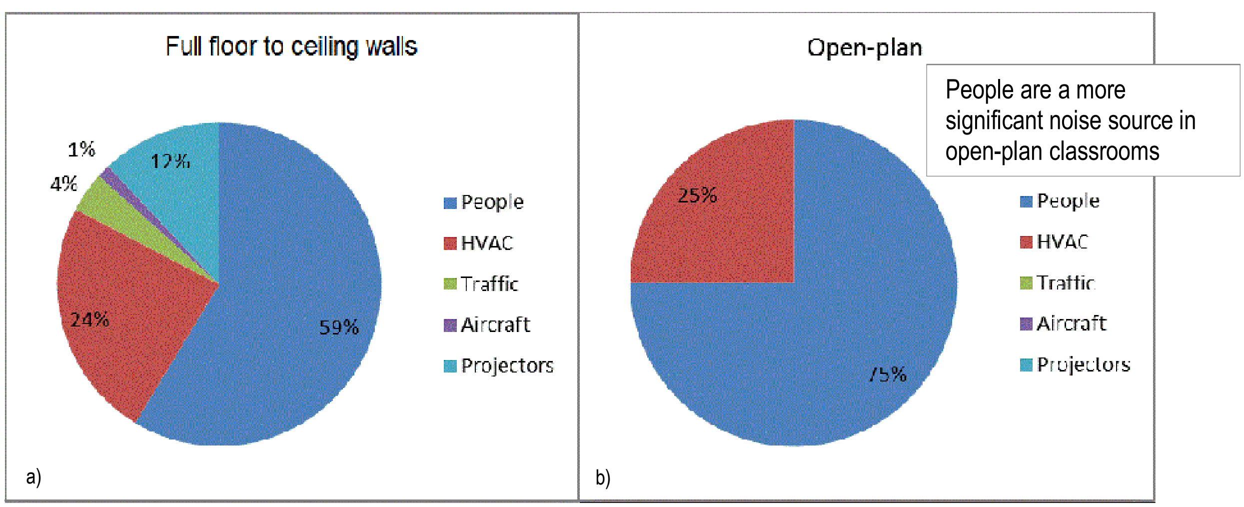


Figure 12. a) Loudest noise sources as perceived by teachers in classrooms with full floor to ceiling walls. b) Loudest noise sources as perceived by teacher in open-plan classrooms.

5. What would you say is the loudest source of background noise in your classroom?

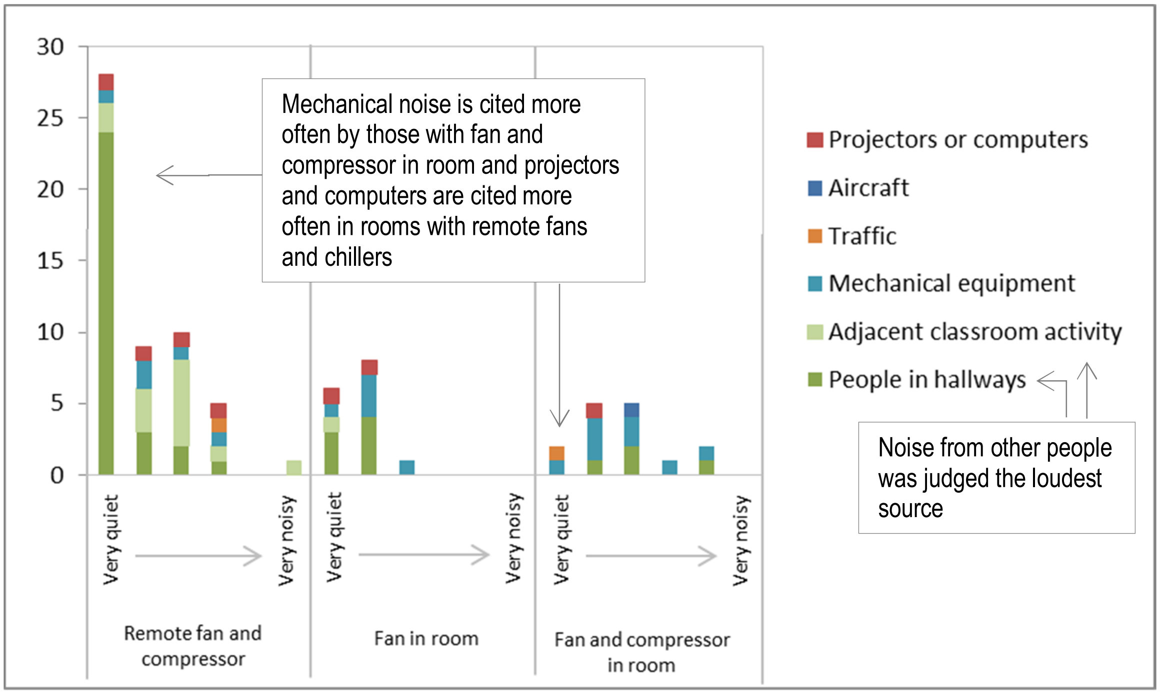


Figure 13. Loudest noise source by HVAC type and perceived noisiness.

6. How often does noise from the heating and air conditioning system prevent students from hearing what you have to say (or require you to repeat yourself)?

7. How often does noise from the heating and air-conditioning system prevent you from hearing what your students have to say (or requires them to repeat themselves)?

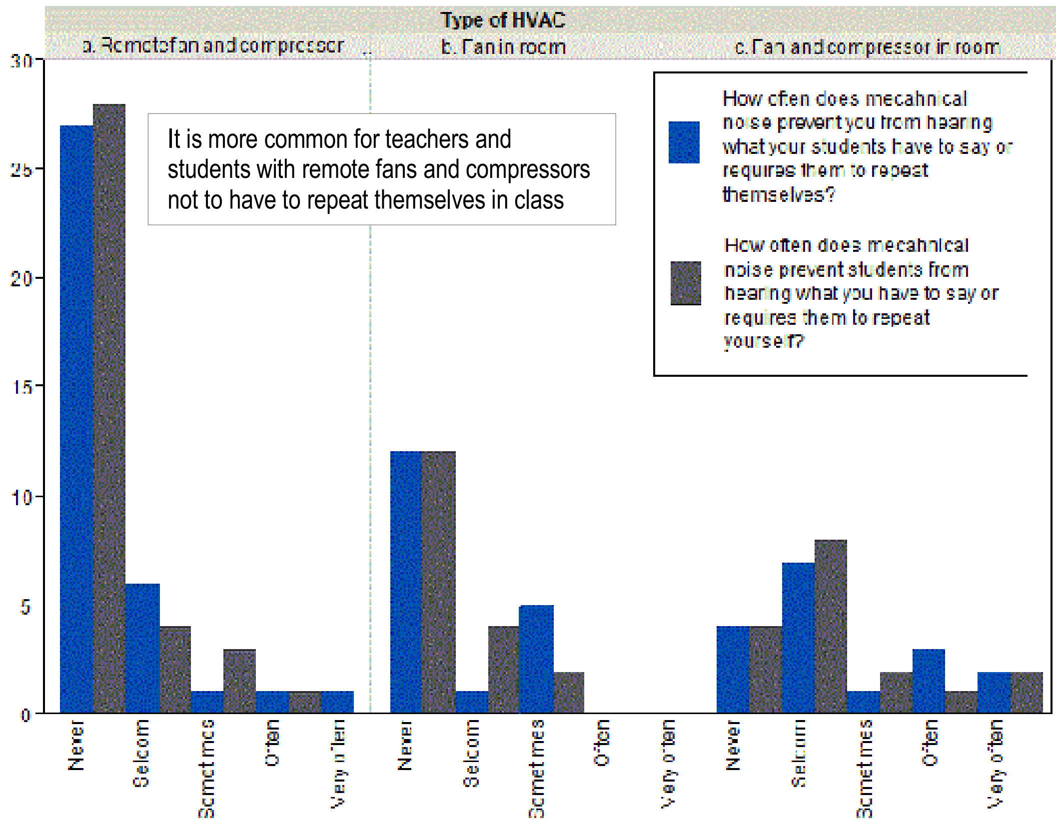


Figure 14. How often noise prevents communication between the teacher and the students in a classroom by HVAC type.

Table 23. Count and percentages per HVAC type to "How often does noise prevent students from hearing what you have to say or requires you to repeat yourself?"

	Never	Seldom	Sometimes	Often	Very often	
a. Remote fan and compressor	28 78%	4 11%	3 8%	1 3%	0 0%	36 51%
b. Fan in room	12 67%	4 22%	2 11%	0 0%	0 0%	18 25%
c. Fan and compressor in room	4 24%	8 47%	2 12%	1 6%	2 12%	17 24%
	44 62%	16 23%	7 10%	2 3%	2 3%	71

Table 24. Count and percentages per HVAC type to "How often does noise prevent you from hearing what your students have to say or requires them to repeat themselves?"

	Never	Seldom	Sometimes	Often	Very often	
a. Remote fan and compressor	27 75%	6 17%	1 3%	1 3%	1 3%	36 51%
b. Fan in room	12 67%	1 6%	5 28%	0 0%	0 0%	18 26%
c. Fan and compressor in room	4 24%	7 41%	1 6%	3 18%	2 12%	17 24%
	43 61%	14 20%	7 10%	4 6%	3 4%	71

Even though the distribution for questions 6 and 7 was very similar, it is noticeably more common, in the teachers' opinion, for students to have to repeat themselves to teachers in the noisy classrooms than for the teachers to do it.

8. What makes air-conditioning noise interfere with classroom activities?

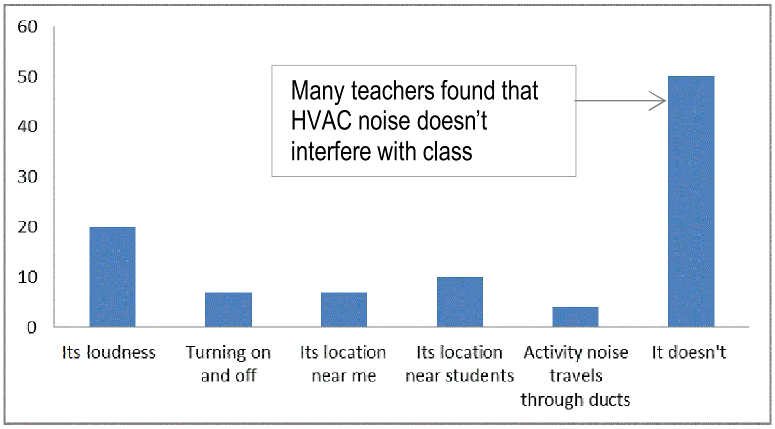


Figure 15. Reasons for HVAC noise to interfere with class

9. If your classroom is noisy, do you adjust your teaching strategies to compensate?

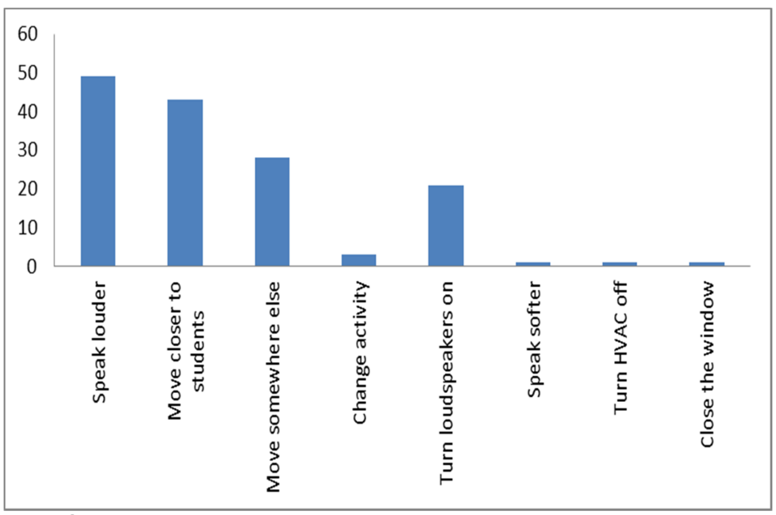


Figure 16. Strategies used by teachers to compensate for background noise.

10. How important do you think it is to reduce the background noise in your classroom?

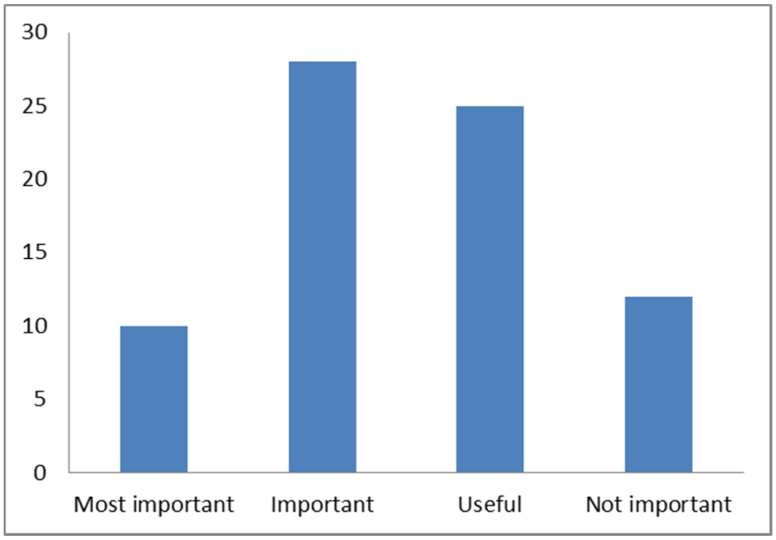


Figure 17. Importance given by teachers to the reduction of background noise in the classroom.

11. Do you think noise in the classroom affects learning? How so?

When asked this open-ended question, respondents volunteered the following issues, grouped into categories populated with example quotations.

Noise impairs communication (12 responses), for example:

"Background noise interferes with the students' and teachers' ability to hear each other clearly."

". . . Students have difficulty hearing other students with quiet voices"

". . . if students can't hear instruction or each other, learning is impacted greatly"

Noise impairs concentration (25 responses), for example:

" . . . It can cause kids to stare, not listen, daydream, or even put them to sleep."

". . . I personally am very sensitive to background noise, so I can imagine that there are at least some students who have a hard time concentrating and paying attention when there is background noise in the classroom."

". . . The turning on and off made it nosier in the classroom and harder for kids to focus on me at times"

Noise impedes learning in children with special needs (4 responses), for example:
"It triggers a meltdown in my autistic student."
". . . many children are sensitive to noise and any extra noise is a distraction. Also, with the large number of children who suffer from periodic, temporary hearing loss due to ear infections, extra noise in the classroom prevents them from hearing instruction."
"For ADD and ADHD children, noise in the classroom would be a nightmare, as well as for the ESL students."

Miscellaneous design issues (3 responses), for example:
"Our classrooms are open to three other rooms through a hallway without doors. About twice each week I have to stop and redirect my students to our task when another classroom is doing something different."
"Our classrooms are built with audio enhancement systems. Noise is not an issue in my classroom."

Mechanical noise not particularly important to address (18 responses), for example:
"Loud noises do affect learning but small noises like a computer or an AC do not. . . children need to be taught that that is life. There are people and noises that are all around us that we may not like but we have to learn to deal with it and do our jobs."
"I think that the absence of background noise is distracting to the students. They live in a world where there is always noise—silence is unusual for them. I often play music while the students are working to enhance their performance."
". . . noise in isolation becomes a greater problem versus noise that is constant, like a child who snorts or sniffs through a test or the noise of a random pencil sharpener. . . constant noise often becomes white noise and you don't end up hearing it. . . like a window unit air conditioner . . . sometimes it is a comfort."

12. Do you ever talk to your principal or administrator about noise from heating and air conditioning system?

The great majority of responses suggested that noise is either not important enough or appropriate to bring up with school administrators, and for the very few cases where it was brought up, it seems little was done to address noise (3 responses). For example:

"The principal is very supportive, but she can't do anything about it."

"I spoke to the office and a work order was put in, but it still does it. The teacher before me also complained and it never got repaired."

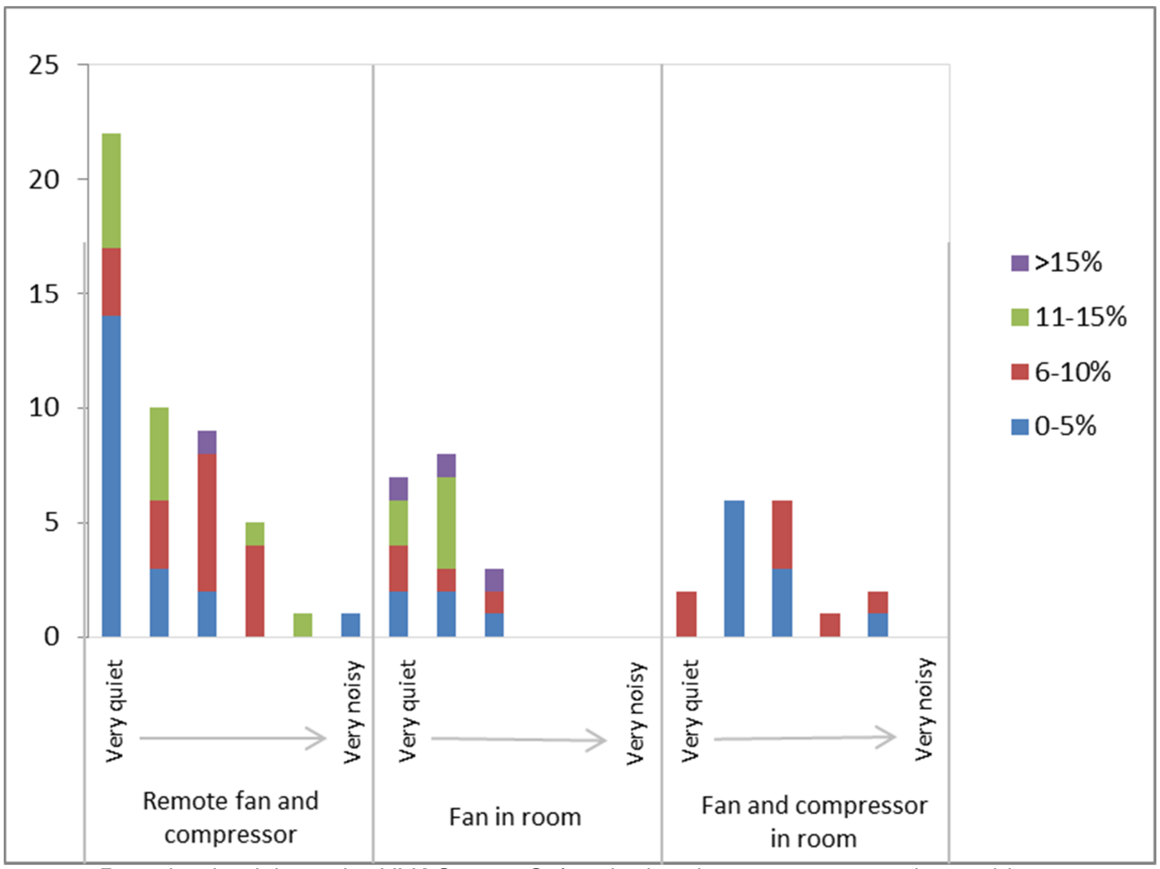


Figure 18. Perceived noisiness by HVAC type. Colors in the chart represent student achievement (percentage of students at top level in a school)

V. DISCUSSION AND CONCLUSION

Even when prompted with opportunities to evaluate noise, teachers in the survey were often unconcerned with their classroom cooling system noise, and when asked about the source of bothersome noise, teachers were likely to identify other students (in hallways, adjacent classrooms, and their classrooms) as the culprits, rather than fixed sources like mechanical equipment. Only one study participant out of 87 labeled his room as “very noisy” without students, and only three out of 87 labeled their rooms “noisy” without students. This was in stark contrast to this study’s forerunner, which suggested student achievement drop-off in the schools with the noisiest types of systems. This suggests that acoustics researchers judge classrooms to be noisy at a far higher rate than the sample of teachers surveyed in this analysis. Relative to the first study, a disproportionate number of responders in this study came from schools with the quietest types of systems (remote fan and remote compressor), which may explain the inconsistency. While overall teachers judged their empty classrooms to be quiet, those in schools with noisier cooling systems types were more likely to think their classrooms noisy.

Few (10%) respondents reported partial-height walls, the kind that separate classrooms from one another visually, but not aurally. Nearly all teachers surveyed use classroom projectors regularly, prompting a need for more study in classroom projector acoustical impact. Because experience suggests that some projectors are far noisier than others, perhaps future classroom design standards should adopt limits to projector noise.

VI. REFERENCES

Acoustical Society of America (2002). “Classroom acoustics”. Retrieved October 12, 2009, from http://asa.aip.org/classroom/booklet.html

Bradley, J. S. (2002). “Acoustic design of rooms for speech” Construction Technology Update. 51.

Bronzaft, A. L. and McCarthy, D. P. (1975). "The effect of elevated train noise on reading ability". Environment and Behavior, 7(4), 517-528.

Cohen, S. Evans, G. W., Krantz, D. S., Stokols, D. & Kelly, S. (1981). "Aircraft noise and children: longitudinal and cross-sectional evidence on adaptation to noise and the effectiveness of noise abatement". Journal of Personality and Social Psychology. (40), 331-345.

Dockrell, J. E. and Shield, B. M. (2006). "Acoustical barriers in classrooms: The impact of noise on performance in the classroom". British Educational Research Journal, 32(3), 509–525

Earthman, G. I. (2002). "School facility conditions and student academic achievement". Los Angeles, CA: UCLA's Institute for Democracy, Education, & Access (IDEA).

Elliot, L. L. (1982). "Effects of noise on perception of speech by children and certain handicapped individuals". Sound and vibration, 16, 10-14.

Grebennikov, L. (2006). "Preschool teachers' exposure to classroom noise". International Journal of Early Years Education, 14 (1). pp. 35–44

Heschong, L. (1999). "Daylighting in schools: An investigation into the relationship between daylight and human performance". Pacific Gas and Electric Company.

Heschong, L. (2003). "Window and classrooms: A study of student performance and the indoor environment". Integrated Energy Systems, California Energy Commission.

Hygge, S., Evans, G. W. and Bullinger, M. (2002). "A prospective study of some effects of aircraft noise on cognitive performance in schoolchildren". Psychological Science, 13(5), 469-474.

Jacobs, K. (2009). "House bill # 443: An act relative to the consideration of ergonomically designed school buildings". General Court of Massachusetts public hearing. October 6, 2009.

Jaramillo, A. M. and Ermann, M. G. (2012). "Linking HVAC type noise and student achievement" InterNoise and NoiseCON Conference Proceedings, New York City NY, 3973-4937

Maroko & Shwe, Inc., and Schaffer Acoustics Inc. (2005). "HVAC systems acoustical, cost & energy study for the Los Angeles Unified School District".

Nelson, P. B. and Soli, S. (2000). “Acoustical barriers to learning: Children at risk in every classroom”. Language, Speech and Hearing Services in Schools, (31), 356-361.

Nelson, P., Kohnert, K., Sabur, S., Shaw, D. (2005). “Classroom noise and children learning through a second language: Double jeopardy? Language, Speech, and Hearing Services in Schools. (36), 219–229

Ronsse, L. M. and Wang, L. M. (2009). “Acoustics of elementary school classrooms: Correlations of varying background noise level and reverberation time to student achievement”. InterNoise Conference Proceedings. Ottawa, Canada.

Shield, B. M. and Dockrell, J. E. (2007). “The effects of environmental and classroom noise on the academic attainments of primary school children”. Journal of the Acoustical Society of America, 123 (1), 133-144.

Siebein, G., Gold, M.A., Ermann, M. (2000). “Ten ways to provide a high-quality acoustical environment in schools”. Language, Speech, and Hearing Services in Schools. (31), 376-384

Siebein, G. W. and Likendey, R. M. (2004). “Acoustical case studies”. ASHRAE Journal.

Stansfeld, S. A., Berglund, B., Clark, C., Lopez-Barrio, I., Fischer, P., Öhrström, E. … Berry, B. F. (2005). “Aircraft and road traffic noise and children’s cognition and health: A cross-national study”. Lancet, 365, 1942-1949.

Vilatarsana, G. (2004). “The environmental noise exposure of schools around Heathrow” (MS Thesis). South Bank University. London, UK.

Zentall, S. S. and Shaw, J. H. (1980). “Effects of classroom noise on performance and activity of second-grade hyperactive and control children”. Journal of Educational Psychology, 72 (6), 830-840.

Zusman, A. F. (2007). “Findings of the FICAN pilot study on the relationship between aircraft noise reduction and changes in standardized test scores”. Federal Interagency Committee on Aviation Noise.

CHAPTER 5. SUMMARY

The proper acoustic design of a classroom is not a mystery. There are clear recommendations in ASHA manuals, ANSI/ASA standard S12.60 and other sources; however, in most cases there is no enforcement of these basic standards required for an appropriate acoustic environment. I believe the lack of compulsory regulations and enforcement is due to the lack of enough hard data to support the belief that noise has a detrimental effect on student achievement. Teachers, as well as the students, find ways to adapt to any environment.

The appropriate design of HVAC systems at schools from an acoustical point of view although it is a complex task, is not impossible. It is more difficult to correct once it has been done incorrectly and is already built. For this reason it is important to educate designers and builders in the best acoustic practices.

Elementary schools in this Florida district were found to have been built or undergone the last renovation during the 60s and 70s. This study has shown the consequences to student performance of outdated and unfitted facilities. These range from old technology and overcrowding to poor building systems. Noise in the classroom is but one of those conditions that a poorly designed or outdated school facility possesses that contribute to low student achievement. It was also found that the schools of lower socio-economic level are more likely to have the worst choice of mechanical system, and these children's achievement is already impacted by their socio-economic level. Also, doubly penalized are children speaking on a second language which conform a high portion of elementary school students in the studied district, but are also a significant percentage in the entire US.

It is the job of architects, builders and facility planners to design and build appropriate schools up to today's standards. Schools retrofitted by acoustic, lightning or other specialists are not necessarily as good as those planned ahead to account for good ergonomics. It is surprising to find that school teachers are not more aware of their own noise exposure at those schools with noisy mechanical systems, but are generally aware of the possible effects of noise in student performance. Noise sources that produce annoyance tend to be more easily recognized, for example tonal, intermittent noises. However, this study found that the broad band, constant levels of mechanical systems with a local compressor and fan can be detrimental to student performance. This finding suggests that more education to teachers and school personnel is necessary in order to overcome the current situation at schools. A teacher with a window unit air conditioning could choose to turn it off in a not-so-hot day if she or he knew the consequences of the constant rumble of the running compressor next to the students, at least during critical communication times in class.

REFERENCES

Acoustical Society of America. (2002). *Classroom acoustics*. Retrieved October 12, 2009, from http://asa.aip.org/classroom/booklet.html

Aiello, J.R., Nicosia, G. & Thompson, D. E. (1979). Physiological, social and behavioral consequences of crowding on children and adolescents. *Child Development, 50(1)*, 195 – 202.

American National Standards Institute. (2002). *Standard 12.60-2002: Acoustical performance criteria, design requirements, and guidelines for schools*.

Avsar, Y. & Gonullu, T. (2010). The influence of indoor acoustical parameters on student perception in classrooms. *Noise Control Eng. J., 58*(3), 310-318

Bell, P. A. & Baron, R. A. (1976). Aggression and heat: The mediating role of negative affect. *Journal of Applied Social Psychology, 6*(1)*,* 18 – 30.

Bess, F. H., Sinclair, J. S., & Riggs, D. (1984). Group amplification in schools for the hearing impaired. *Ear and Hearing,* 5, 138–144.

Bradley, J. S. (1985). *Uniform derivation of optimum conditions for speech in rooms*. National Research Council of Canada. BRN 239.

Bradley, J. S. (1986). Speech intelligibility studies in classrooms. *Journal of the Acoustical Society of America*, *80*(3), 846–854.

Bradley, J. S. (2002). Acoustic design of rooms for speech. *Construction Technology Update, 51.*

Bronzaft, A. L. (1981). The effect of a noise abatement program on reading ability. *Journal of Environmental Psychology*, 1, 215 – 222.

Bronzaft, A. L. & McCarthy, D. P. (1975). The effect of elevated train noise on reading ability. *Environment and Behavior,* 7, 517 – 527

Buddin, R. (2011). Measuring teacher and school effectiveness at improving student achievement in Los Angeles elementary schools. *Los Angeles Times*.

Cash, C. S. (1993). *Building condition and student achievement and behavior* (unpublished doctoral dissertation). Virginia Polytechnic Institute and State University.

Center for immigration studies analysis, *Current population survey*, (March 2007).

Choi, C. Y., McPherson, B. (2005). Noise levels in Hong Kong primary schools: Implications for classroom listening. *International Journal of Disability, Development and Education, 52* (4), 345–360

Cohen, S., Evans, G. W., Krantz, D. S., Stokols, D. & Kelly, S. (1981). Aircraft noise and children: longitudinal and cross-sectional evidence on adaptation to noise and the effectiveness of noise abatement. *Journal of Personality and Social Psychology*. 40, 331-345.

Cohen, S., Evans, G., Krantz, D. S., & Stokes, D. (1980). Psychological, motivational, and cognitive effects of aircraft noise on children. *American Psychologist*, 35, 231- 243.

Crandell, C. C., & Bess, F. (1987) Developmental changes in speech recognition in noise and reverberation. *ASHA 29,* 170.

Crandell, C. C., & Smaldino, J. J. (1994). An update of classroom acoustics for children with hearing impairment. *The Volta Review*, *96*, 291–306.

Crandell, C. C. & Smaldino, J. J. (2000) Classroom acoustics for children with normal hearing and with hearing impairment. *Language, Speech and Hearing Services in Schools*, 31, 362 – 370

Department of Health Services. (1981). *Effects of noise on academic achievement and classroom behavior*. (Report No. FHWA/CA/DOHS-81/01). State of California.

Dockrell, J. E. & Shield, B. M. (2006). Acoustical barriers in classrooms: The impact of noise on performance in the classroom. *British Educational Research Journal, 32* (3), 509 – 525

Duffy, P. M. (1992). *Classrooms and their users: A conceptual mapping of research on the physical environment of schools (school environment).* (unpublished doctoral dissertation), The Pennsylvania State University.

Duckworth, A. L., Quinn, P. D. & Tsukayama, E. (2012). What No Child Left Behind leaves behind: The Roles of IQ and self-control in predicting standardized achievement test scores and report card grades. *Journal of Educational Psychology, 104* (2), 439-451

Dunn, R. (1987). Research on instructional environments: Implications for student achievement and attitudes. *Professional School Psychology, 2*(1), 43 – 52.

Earthman, G. I. (November, 1998). The impact of school building condition and student achievement and behavior. Paper presented at the international conference: The Appraisal of Educational Investment. Luxembourg: European Investment Bank and Organization for Economic Cooperation Development.

Earthman, Glen I. (2002). *School Facility Conditions and Student Academic Achievement*. Los Angeles, CA: *UCLA's Institute for Democracy, Education, & Access (IDEA).*

Elliott, L. (1979). Performance of children aged 9 to 17 years on a test of speech intelligibility in noise using sentence material with controlled word predictability. *Journal of the Acoustical Society of America, 66(3),* 651–653.

Elliott, L. (1982). Effects of noise on perception of speech by children and certain handicapped individuals. *Sound and Vibration, 71 (12),* 9–14.

Evans, G. W. & Maxwell, L. E. (1997). Chronic noise exposure and reading deficits: The mediating effects of language acquisition. *Environment and Behaviour, 29*(5), 638 – 656.

Fernandez, R. R. & Timpane, P. M. (1995). *Bursting at the seams: Report of the citizens' commission on planning for enrollment growth*. New York: Office of the Chancellor, New York City Board of Education.

Finn, J. D. & Achilles, C. M. (1999). Tennessee's size class study: Findings, implications, misconceptions. *Educational Evaluation and Policy Analysis, 21*(2), 97 – 109.

Grebennikov, L. (2006). Preschool teachers' exposure to classroom noise. *International Journal of Early Years Education, 14* (1). pp. 35–44

Green, K., Pasternak, B. & Shore, B. (1982). Effects of aircraft noise on reading ability of school age children. *Archives of Environmental Health*, 37, 24 – 31.

Haines, M. M., Stansfeld, S. A., Head, J. & Job,R. F. S. (2002). Multi-level modeling of aircraft noise on performance tests in schools arounf Heathrow Airport London. *Journal of Epidemiology and Community Health, 56*, 139 – 144.

Harner, D. P. (1974). Effects of thermal environment on learning skills. *CEFP Journal*, 24, 367 – 76.

Heschong, L. (1999). Daylighting in schools: An investigation into the relationship between daylight and human performance. *Pacific Gas and Electric Company*.

Heschong, L. (2003). Window and classrooms: A study of student performance and the indoor environment. *Integrated Energy Systems, California Energy Commission*.

Heath, G. A. & Mendell, M. J. (2004). Do indoor environments in schools influence student performance? A review of the literature. *Lawrence Berkeley National Laboratory.*

Hetu, R., Truchon-Gagnon, C. & Bilodeau, S. A. (1990). Problems of noise in school settings: A review of literature and the results of an exploratory study. *Journal of Speech Language Pathology and Audiology, 14*(3), 31 – 38.

Higgins, S., Hall, E., Wall, K., Woolner, P. & McCaughey, C. (2005). *The impact of school environments: A literature review*. London: The Design Council.

Hodgson, M. (1999). Experimental investigation of the acoustical characteristics of university classrooms. *Journal of the Acoustical Society of America*, 106(4), 1810–1819.

Houtgast, T. (1981). The effect of ambient noise on speech intelligibility in classrooms. *Applied Acoustics,* 14, 15–25.

Hyatt, C. L. (1982*). The effect of jet aircraft noise on student achievement and attitude toward classroom environment.* (unpublished doctoral dissertation), Seattle University.

Hygge, S. (2000). Effects of aircraft noise on children's cognition and long term memory. *FICAN symposium*, San Diego, California.

Hygge, S., Boman, E. & Enmarker, I. (2003). The effects of road traffic noise and meaningful irrelevant speech on different memory systems. *Scandinavian Journal of Psychology*, 44, 13 – 21.

Hygge, S., Evans, G. W. & Bullinger, M. (2002). A prospective study of some effects of aircraft noise on cognitive performance in school children. *Psychological Science, 13*(5), 469 – 474.

Jacobs, K. (2009). *House bill # 443: An act relative to the consideration of ergonomically designed school buildings.* General Court of Massachusetts public hearing. October 6, 2009.

Jaramillo, A. M. and Ermann, M. G. (2012). Linking HVAC type noise and student achievement. *InterNoise and NoiseCON Conference Proceedings*, New York City NY, 3973-4937

Johansson. C. R. (1983). Effects of low intensity, continuous, and intermittent noise on mental performance and writing pressure on children with different intelligence and personality characteristics. *Ergonomics, 26*(3), 275 – 288.

Johnson, C. E. (2000). Children's phoneme identification in reverberation and noise. *Journal of Speech, Language, and Hearing Research 43,* 144–157.

Keaton, P. (National Center for Education Statistics) (2012). *Numbers and types of public elementary and secondary schools from the common core of data: School year 2010–11*. U.S. Department of Education.

Kevan, S. M & Howes, J. D. (1980). Climatic conditions in classrooms. *Educational Review, 32*(3), 281 – 292.

Knecht, H.A., Nelson, P.B., Whitelaw, G. M. & Feth, L. L. (2002). Background Noise Levels and Reverberation Times in Unoccupied Classrooms: Predictions and Measurements. *American Journal* of Audiology. 11, 65-71

Knudsen, V. O. & Harris, C. M. (1950). *Acoustical designing in architecture*. New York: John Wiley & Sons, Inc.

Kuller, R. & Lindsten, C. (1992). Health and behavior of children in classrooms with and without windows. *Journal of Environmental Psychology,* 12, 305 – 317.

Laird, D. A. (1930). The effects of noise: A summary of experimental literature. *Journal of the Acoustical Society of America*. 1, 256-61.

Lanham III, J. W. (1999). *Relating building and classroom conditions to student achievement in Virginia's elementary schools* (unpublished doctoral dissertation). Virginia Polytechnic Institute & State University, Blacksburg, VA.

Lowe, J. M. (1990). *The interface between educational facilities and learning climate in three elementary schools* (unpublished doctoral dissertation). Texas A&M University, College Station, TX.

Lundquist, P., Holmberg, K. & Landstrom, U. (2000). Annoyance and effects on work from environmental noise at school. *Noise and Health,* 28, 39-46

Manlove, E. E., Frank, T & Vernon-Feagans L. (2001). Why should we care about noise in classrooms and child care settings? *Child & Youth Care Forum*, 30(1), 55-64.

Maroko & Shwe, Inc. and Schaffer Acoustics Inc. (2005). *HVAC systems acoustical, cost & energy study for the Los Angeles Unified School District*.

Maxwell, L. & Evans, G. (2000). The effects of noise on pre-school children's pre-reading skills. *Journal of Environmental Psychology*, 20, 91 – 97.

Morgan, J.B. (1917). The effect of sound distractions upon memory. *American Journal of Psychology*, 28, 191-208.

Mull, T. E. (1998). *HVAC: Principles and applications manual*. New York: McGraw-Hill.

Nabelek, A. & Robinson, P. (1982). Monaural and binaural speech perception in reverberation for listeners of various ages. *Journal of the Acoustical Society of America, 71(5)*, 1242–1248.

Nelson, P. B. (2000). Improving acoustics in American schools. *Language, Speech, and Hearing Services in Schools*, 31, 354-355

Nelson, P., Kohnert, K., Sabur, S., Shaw, D. (2005). Classroom noise and children learning through a second language: Double jeopardy? *Language, Speech, and Hearing Services in Schools.* 36, 219–229

Nelson, P. B., Soli, S. (2000). Acoustical barriers to learning: Children at risk in every classroom. *Language, Speech and Hearing Services in Schools, 31*, 356-361.

Newman, M. (2009). *Post-occupancy evaluation of primary schools: A multistakeholder perspective* (unpublished doctoral thesis). Coventry University.

Nicklas, M. H. & Bailey, B. B. (1995). Student Performance in Daylit Schools. *Innovative Design.*

Picus, L.O., Marion, S. F., Calvo, N. & Glenn, W. J. (2005). Understanding the relationship between student achievement and the quality of educational facilities: Evidence from Wyoming. *Peabody Journal of Education*, 80(3), 71 – 95.

Plympton, P., Conway, S. & Epstein, K. (2000). Daylighting in schools: Improving student performance and health at a price schools can afford. *American Solar Energy Conference.* Madison, Wisconsin, National Renewable Energy Laboratory.

Rivera-Batiz, F. L. & Marti, L. (1995). *A school system at risk: A study of the consequences of overcrowding in New York City public schools*. New York: Institute for Urban and Minority Education, Teachers College, Columbia University.

Ronsse, L. M. and Wang, L. M. (2009). Acoustics of elementary school classrooms: Correlations of varying background noise level and reverberation time to student achievement. *InterNoise Conference Proceedings*. Ottawa, Canada.

Ronsse, L. M. & Wang, L. M. (2010). AB-10-C037: Effects of noise from building mechanical systems on elementary school student achievement. *ASHRAE Transactions*, 116 (2), 347-354

Santos, F. & Gebeloffny, R., (February 25, 2012). Teacher quality widely diffused, ratings indicate, *The New York Times.*

Shield, B. M. & Dockrell, J. E. (2007). The effects of environmental and classroom noise on the academic attainments of primary school children. *Journal of the Acoustical Society of America, 123*(1), 133 – 144.

Shield, B. M. & Dockrell, J. E. (2008). The effects of environmental and classroom noise on the academic attainments of primary school children. *Journal of the Acoustical Society of America, 123* (1), 133-144

Shield, B. M. & Dockrell, J. E. (2009). The effects of noise on children at school: A review. *Building Acoustics*, (10), 97-116

Siebein, G., Gold, M.A., Ermann, M. (2000). Ten ways to provide a high-quality acoustical environment in schools. *Language, Speech, and Hearing Services in Schools*. 31, 376-384

Siebein, G. W. & Likendey, R. M. (2004). Acoustical case studies. *ASHRAE Journal.*

Stansfeld, S. A., Berglund, B., Clark, C., Lopez-Barrio, I., Fischer, P., Öhrström, E. … Berry, B. F. (2005). Aircraft and road traffic noise and children's cognition and health: A cross-national study. *Lancet, 365*, 1942-1949.

Tanner. K. (2000). The influence of school architecture on academic achievement. *Journal of Educational Administration, 38*(4), 309 – 330.

U.S. Bureau of the Census. (2000). *Languages spoken at home*. Retrieved October 12, 2009, from http://www.census.gov/population/www/socdemo/lang_use.html

Vilatarsana, G. (2004). *The environmental noise exposure of schools around Heathrow* (master thesis). South Bank University. London, UK

Wargocki, P. & Wyon, D. P. (2007). The effects of outdoor air supply rate and supply air filter condition in classrooms on the performance of schoolwork by children. *HVAC&R Research, 13*(2), 165 – 191.

Weinstein, C. S. (1979). The physical environment of the school. *Review of Educational Research, 49* (4), 577 – 610

Zentall, S. S. & Shaw, J. H. (1980). Effects of classroom noise on performance and activity of second-grade hyperactive and control children. *Journal of Educational Psychology*, 72(6), 830-840.

Zusman, A. F. (2007). *Findings of the FICAN pilot study on the relationship between aircraft noise reduction and changes in standardized test scores*. Federal Interagency Committee on Aviation Noise.

APPENDIX A. THE INFLUENCE OF BACKGROUND NOISE IN STUDENT ACHIEVEMENT

Ana Jaramillo - Virginia Tech

Michael Ermann – Virginia Tech

1. Abstract

During our entire life span we spend time in the activity of learning (anything from basic survival skills to highly intellectual processes), but this activity occupies most of the time during the first years of our lives. The classroom becomes then the "official" learning space that is designed to be conducive to this activity. The learning process, regardless of the task difficulty, is not a mechanical one. It requires a mental process, concentration, attention in various degrees. Distractions can be detrimental to the learning. Most of the learning activities that occur at school settings require some kind of oral communication (teacher-student or student-student), and these activities call for appropriate room acoustics. In the presence of high levels of background noise, human beings have other resources to better understand the signal of interest. Those can be visual cues, previous knowledge of the topic, or mental ability to "fill in the blanks" in the received speech. The last two, are abilities that come with age and experience. The purpose of this study is to better assert the importance of acoustics parameters in the design of classrooms, and their relation to student achievement.

2. Introduction

Previous studies (Crandell & Bess, 1987; Elliott, 1979, 1982; Nabelek & Robinson, 1982) have concluded that children have:

- Inefficient, broadband listening strategy
- Inability to put together missing pieces
- Immature weighting of acoustic information
- Increased susceptibility to distracters

- Decreased ability to segregate signals from noise
- Higher effects from excessive reverberation

For these reasons, it is expected that children need better acoustic conditions to fully understand speech. In 2002 ANSI 12.60 was published establishing the first American standard for good classroom acoustics in the United States. It recommends a maximum background noise level of 35 dB(A) and maximum RT of 0.6 seconds (American National Standards Institute, 2002). It also provides minimum sound transmission class (STC) values for noise isolation between spaces.

Studies show that an adult with normal hearing ability needs a signal-to-noise ratio SNR of 6 to 10 dB to understand speech in a noisy setting (Houtgast, 1981). Later studies demonstrated that the ratios needed for children were considerably higher, about 15 to 20 dB (Bradley, 1986; Hodgson, 1999). For children with permanent or temporary hearing loss, still higher ratios are required (Crandell & Smaldino, 1994; Hodgson, 1999).

For the subgroup with English as a Second Language both children and adults require better acoustic conditions to process speech (Nelson et al., 2005). The limited previous knowledge of the language prompts a decreased ability to “fill in the blanks”, handicapping speech understanding. According to the 2000 U.S. Census, 10% of individuals counted were not born in this country. By 2010, it was estimated that one of every five schoolchildren will be a recent immigrant to the United States, and the majority of these children will likely acquire languages other than English at home (U.S. Bureau of the Census, 2000)

Though the standards and studies have been published for decades, the reality continues to part from the recommendations. Problem resolutions have been attempted, but most oriented toward teaching methodology rather than toward space design. This is likely due to lack of awareness by teachers and school administrators. As a first measure teachers try to increase the SNR by increasing their voice levels, causing vocal fatigue and throat problems. A better solution is to decrease the distance between the teacher and the students, but this is not always possible in classrooms (Manlove, Frank, & Vernon-Feagans, 2001). The control of the teacher over the student group influences the activity noise inside the classroom. Technical solutions include curtains and ceiling tiles as inexpensive sound absorbers to help reduce RT and better mechanical systems to decrease noise and also increase SNR. The most effective solutions, though, must come from the design phase of the classroom—from the architecture and construction. An adequate site, distant from busy roads is a very good start (Siebein et al., 2000). Low sound transmission between massive, airtight, walls dividing classrooms, and importantly, between core learning spaces and those devoted to sports, music, A/V, recreation activities, and school gatherings. Mechanical system design is of the greatest importance, because HVAC systems are the primary noise source in classrooms and some systems are much louder than others. Mechanical noise can be reduced by both the use of quieter equipment and better system design, especially as it pertains to forced air heating and cooling.

It should be noted that previous studies conducted in the area of classroom acoustics address the need of the teacher's voice to be fully intelligible for students, as the signal of interest in the classroom. Some of them address as well the need for communication from the students towards the teacher in the form of questions or assessments of content understanding. Very few studies, however, have considered the need for communication between children, which is the cause of much of the incidental learning that occurs during the school day (and especially vital for children with hearing disabilities).

Figure 19. Partial height partitions separate this classroom from adjacent classrooms. Note the daylight coming over the far wall in the image

3. Open-plan Elementary School

The Elementary School selected for this study has an open-plan design. *Partial-height partitions separate the classrooms in this study*. The suburban/small town neighborhood around it does not present high levels of transportation or industry noise. The noise present in the classrooms originates from the mechanical systems, lighting, and, especially, the other activities inside the school. The mechanical room is centrally-located, far from the classroom area. Some noise emanates from the diffusers. Fluorescent lightning, which buzzes audibly, covers the entire ceiling area (the classrooms don't get much daylight, and some get none).

Teachers in the school have developed techniques to cope with the lack of acoustic privacy between classrooms. Quiet activities are necessary all the time, and group control is more important than usual. Teachers interviewed report that the children adapt, but are continuously aware of what's happening in the next classroom.

4. Measurements

The study selected noise isolation class (NIC) for measurements between two adjacent spaces rather than transmission loss (TL) because the classrooms lack floor-to-ceiling partitions. NIC was measured in two 3rd grade classrooms. ASTM standard E336-

09 (Standard Test Method for Measurement of Airborne Sound Attenuation between Rooms in Buildings) was used for the measuring procedures. Reverberation Time measurements were performed as a reference and for possible corrections on the receiving room levels.

Six measurement locations were selected in each room. Noise levels were measured using both pink and white noise (12 measurements per condition). The lights and mechanical systems were on and the occupants were out of the building. RT was measured using pink noise (15 measurements per classroom) and the lights were turned off.

A type 2 CESVA SC160 sound level meter with a Real Time Analyzer and Reverberation Time modes was used for the measurements.

5. Data

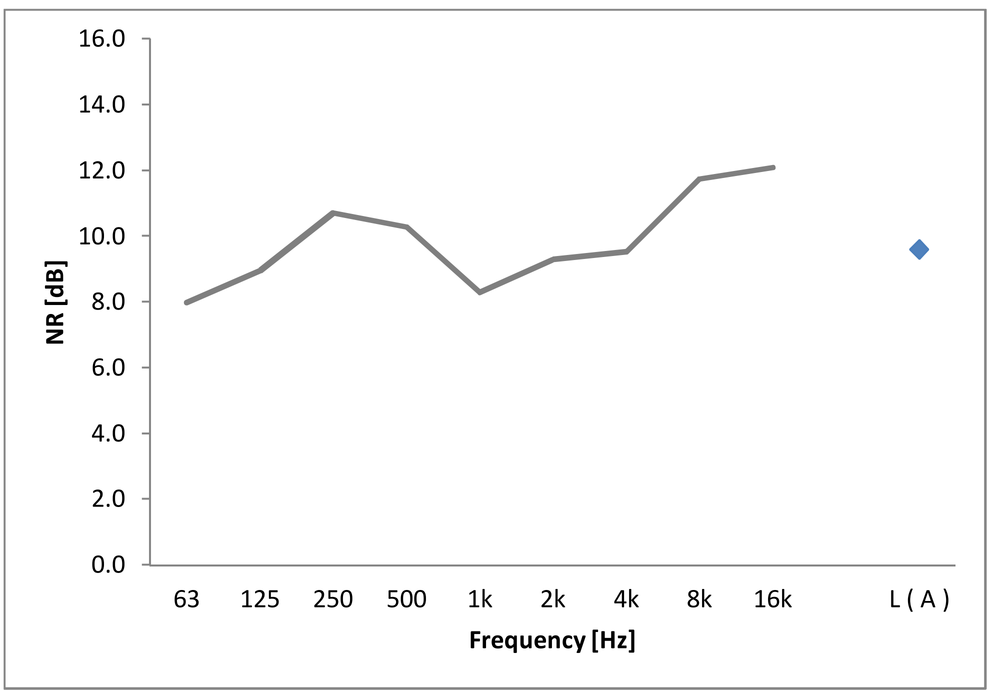


Figure 20. Sound attenuation between rooms (source in room 1).

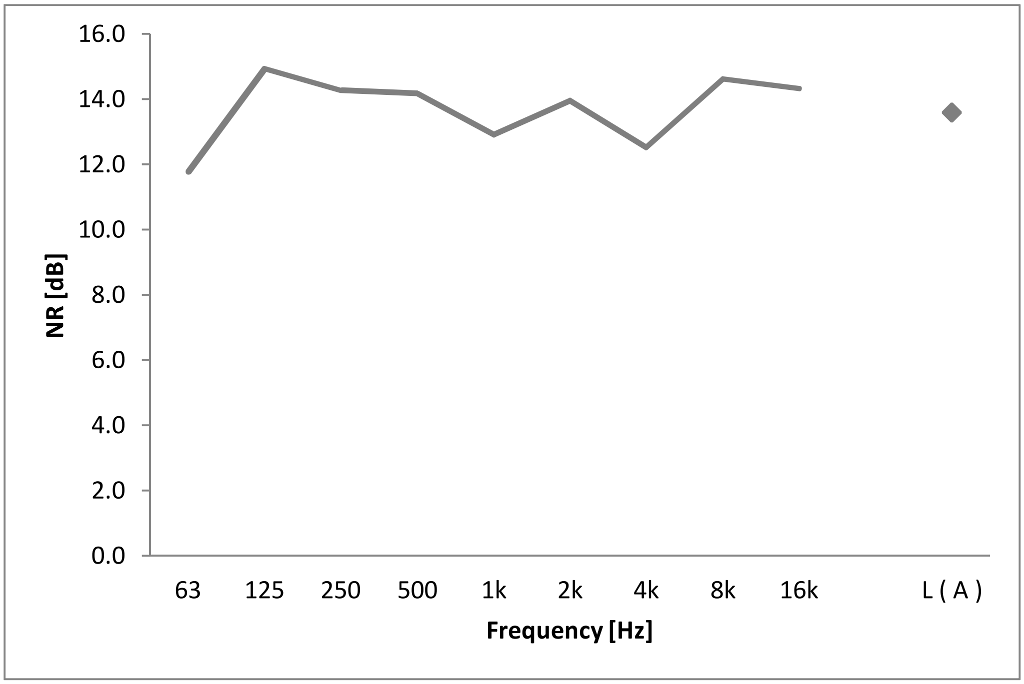


Figure 21. Sound attenuation between rooms (source in room 2).

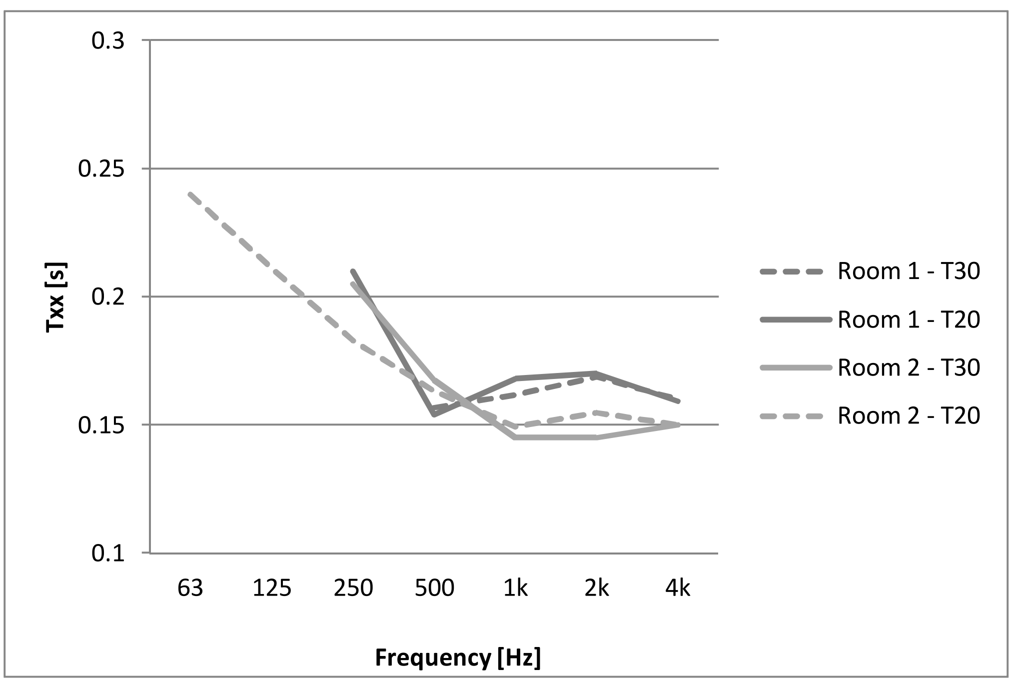


Figure 22. Reverberation times in room 1.

6. Results

Noise measurements show the expected anemic noise isolation results. A maximum of NIC 16 was found when measuring acoustic separation between the two 3rd grade classrooms. ANSI standard 12.60 (2006) recommends a TL of 50 between core learning spaces (recommendations in the literature for TL between classrooms and corridors are generally no lower than 45).

It is clear that the school, in its open-plan classrooms, is far short of the recommended classroom acoustics noise isolation standards, however, the school principal and teachers interviewed don't see noise as being a problem. Are the children adapting to an acoustically-poor space? Do the noise requirements teachers put on students in those classrooms help with concentration or cost beneficial student-to-student interaction? Are the noisy activities that the teachers refrain from doing an important part of the learning process? Qualitative studies are necessary to answer some of these questions. It is not enough to assess the current noise levels in classrooms, or to understand the effects on children's performance. Considering humans' potential for adaptation to adverse conditions we need to better understand the long-term effects of noise exposure and its cost to children's education.

APPENDIX B. HVAC SURVEY

Schools Cooling Systems

Please know that answering this 1-question survey is optional. There is no penalty for non-participation.------ What is the school's name?

What type of mechanical cooling system serves at least 80% of the instructional classrooms in your school?

- ○ BOTH FANS AND COMPRESSORS ARE EXPOSED TO THE CLASSROOM. This includes self-contained DX, unitary, through-the-wall, or window units. The refrigeration cycle occurs in a machine that is located inside the classroom.
- ○ FANS ARE EXPOSED TO THE CLASSROOM BUT COMPRESSORS ARE NOT. This includes remote chillers with local fan coil units in the classrooms themselves, fan coil units above the classroom ceilings, or fan coil units in classroom closets.
- ○ NEITHER FAN NOR COMPRESSOR ARE EXPOSED TO THE CLASSROOM. This includes remote chillers with central AHUs or rooftop units. Ducts are used to bring air from central AHUs to the classrooms.
- ○ NO SINGLE COOLING SYSTEM TYPE SERVES AT LEAST 80 PERCENT OF THIS SCHOOL'S CLASSROOMS.
- ○ I'M NOT CERTAIN THE ANSWER TO THIS QUESTION.
- ◉ other:

Comments

APPENDIX C. TEACHER SURVEY

Teacher Survey

The following survey is part of my doctoral research. It is an unfunded research developed in the School of Architecture at Virginia Tech. The objective of this survey is to gather information from 73 schools in Orange County, FL that might have an effect in improving classroom environments for elementary schools in the US. Please answer the following questions to the best of your knowledge. Your answers are anonymous. Identities or school names won't be mentioned in published results. If you have any questions feel free to contact me or my faculty adviser. Contact information is provided below.

Ana M. Jaramillo, doctoral candidate
anaja@vt.edu. 540 239 6548

Michael Ermann, faculty adviser
mermann@vt.edu. 540 231 1225

Name of your school

How noisy is your classroom without students?
○ Very noisy ○ Noisy ○ Somewhat noisy ○ Somewhat quiet ○ Quiet ○ Very quiet

How long have you been teaching at the current school?

Are there full floor to ceiling walls separating your classroom from adjacent rooms?
○ Full floor to ceiling walls ○ Partial or no walls (open-plan)

Are there projectors or computers used often inside the classroom?
○ Yes ○ Only once in a while ○ No

What would you say is the loudest source of background noise in your classroom?
○ Traffic
○ Aircraft
○ Adjacent classroom activity
○ People in hallways
○ Mechanical equipment (air conditioning, fan)
○ Projectors or computers
◉ Other:

How often does noise from the heating and air-conditioning system prevent students from hearing what you have to say or require you to repeat yourself?
○ Never ○ Seldom ○ Sometimes ○ Often ○ Very often

How often does noise from the heating and air-conditioning system prevents you from hearing what your students have to say or require them to repeat themselves?
○ Never ○ Seldom ○ Sometimes ○ Often ○ Very often

What makes air-conditioning noise interfere with classroom activities? (You may choose more than one answer)
☐ Its loudness
☐ Turning on and off
☐ Its location near me
☐ Its location near the students
☐ Activity noise from other classrooms travels through ducts
☐ It doesn't interfere at all
Other:

If your classroom is noisy, do you adjust your teaching strategies to compensate? (You may choose more than one answer)

- [ ] I speak louder
- [ ] I move closer to students
- [ ] I move to a different location in the classroom
- [ ] I change to an individual activity
- [ ] I turn on the loudspeakers (if available)

Other: ____________

How important do you think it is to reduce the background noise in your classroom?

- ○ The single most important issue to address
- ○ Important but after improving other physical aspects of the classroom
- ○ Useful but not necessary
- ○ Not important at all
- ◉ (optional) Comment: ____________

Do you think noise in the classroom affects learning? How so?

Do you ever talk to your principle or administrator about noise from heating and air-conditioning system?

Do you want to add anything?

THIS IS OPTIONAL. We might want to contact you to elaborate in one of your answers or other topics you commented on, if you agree to be contacted in the future please enter your email address and phone number below. Your answers will still be anonymous.

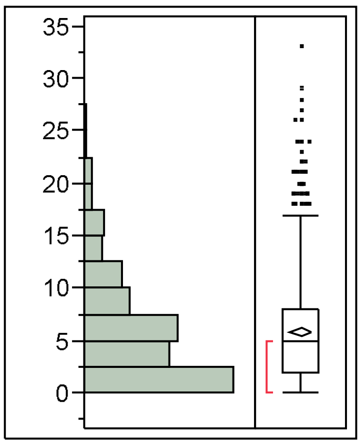
Submit

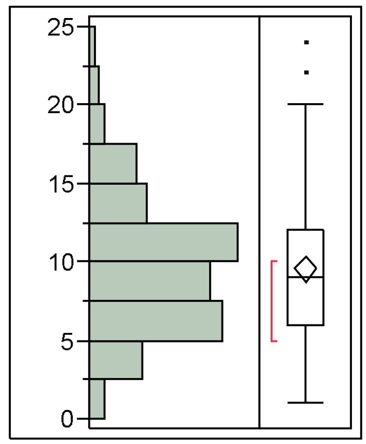
APPENDIX D. DATA DISTRIBUTION

Distribution of data for entire socio-economic range

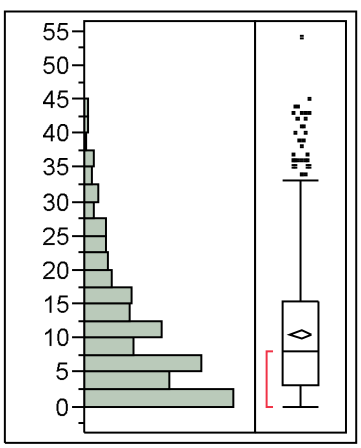
Distribution of data for schools with 20-50% of students receiving free or reduced lunch

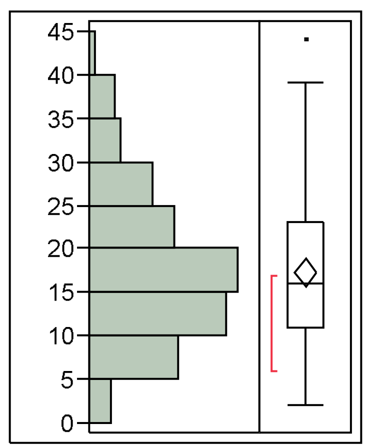
% Students at top reading achievement level



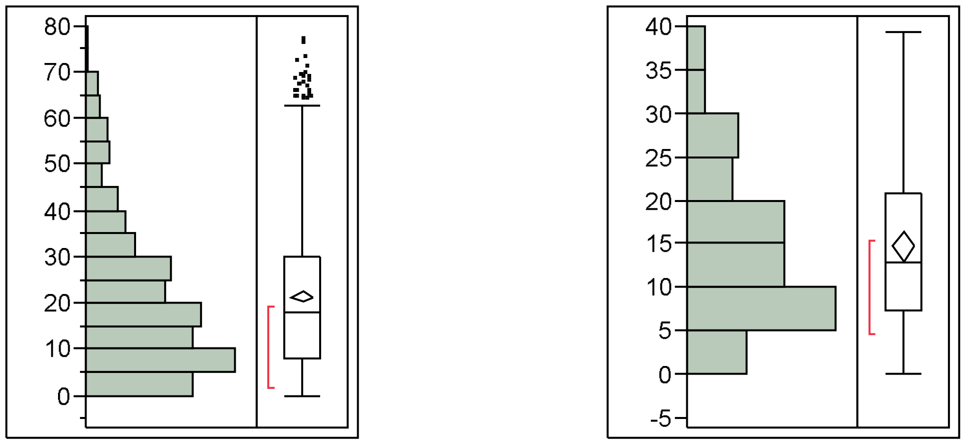


% Students at top math achievement level

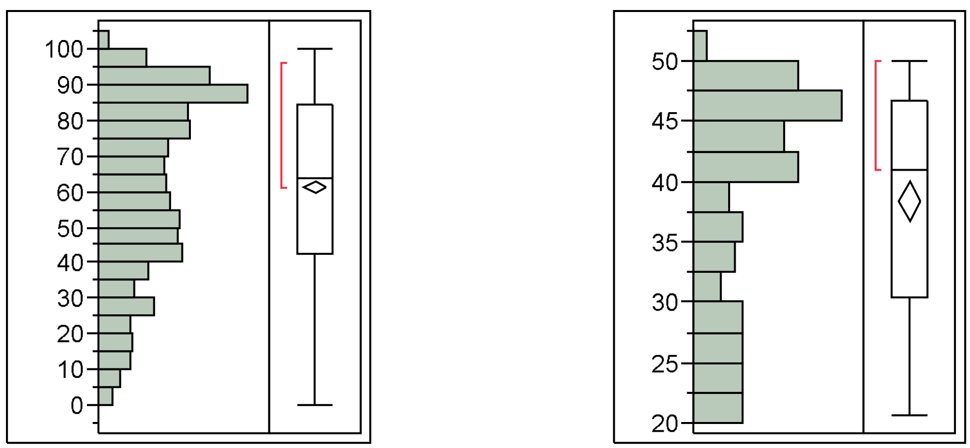




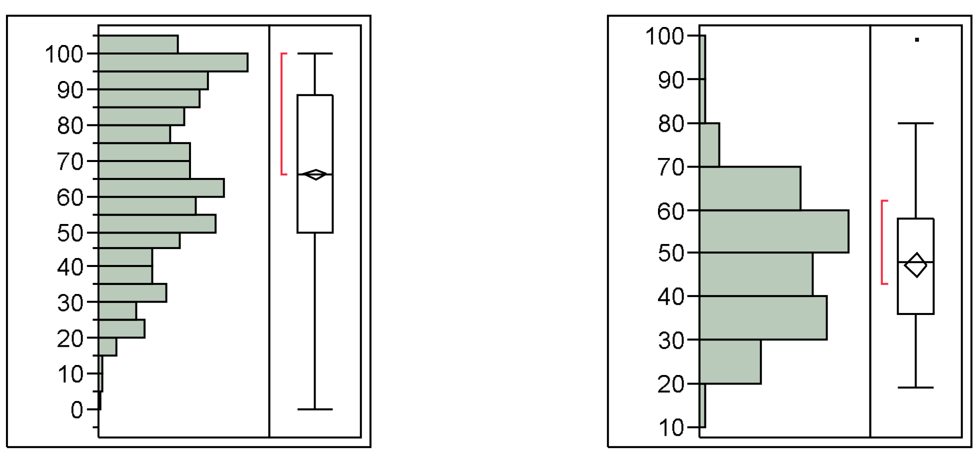
% ESL students



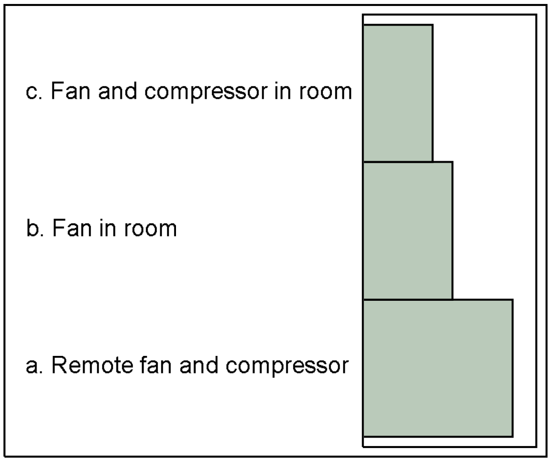
% Students receiving free or reduced Lunch

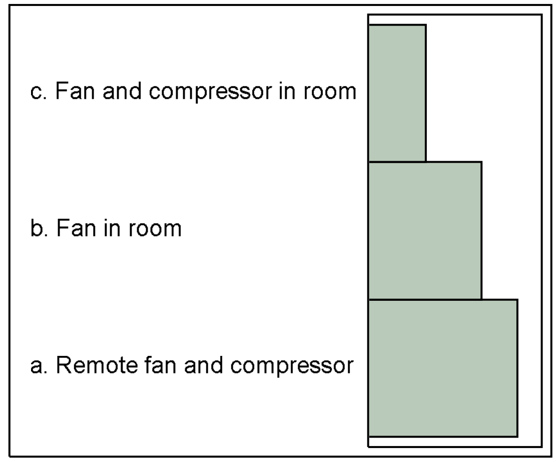


% Students belonging to racial minorities (non-white)



HVAC Type

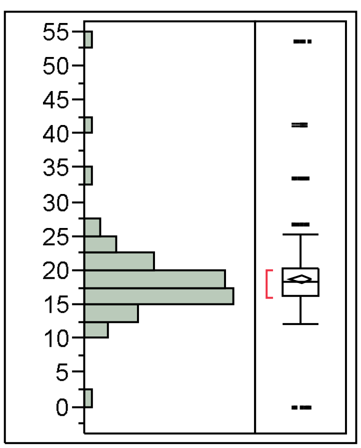


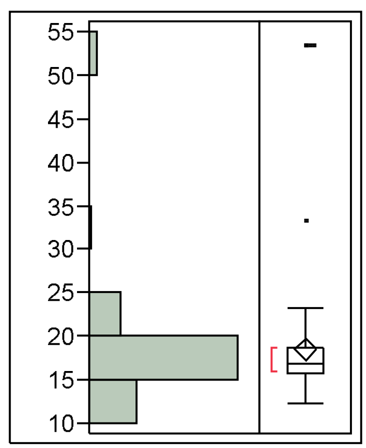


Level	Count	Prob
a.	224	0.48
b.	136	0.29
c.	104	0.22
Total	464	1.00

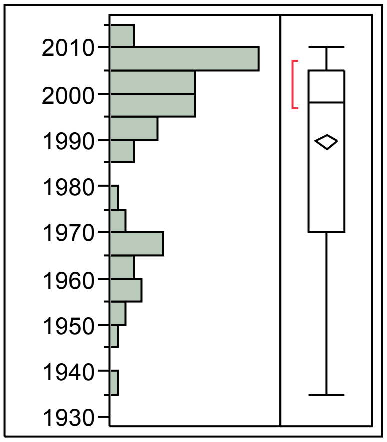
Level	Count	Prob
a.	54	0.47
b.	41	0.35
c.	21	0.18
Total	116	1.00

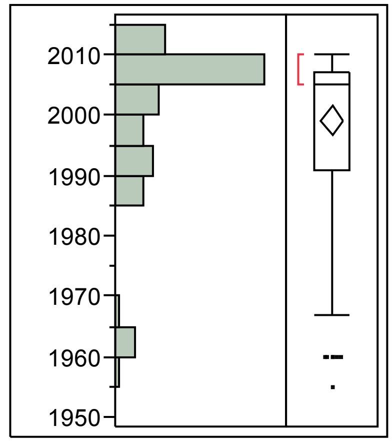
Class size (2010)



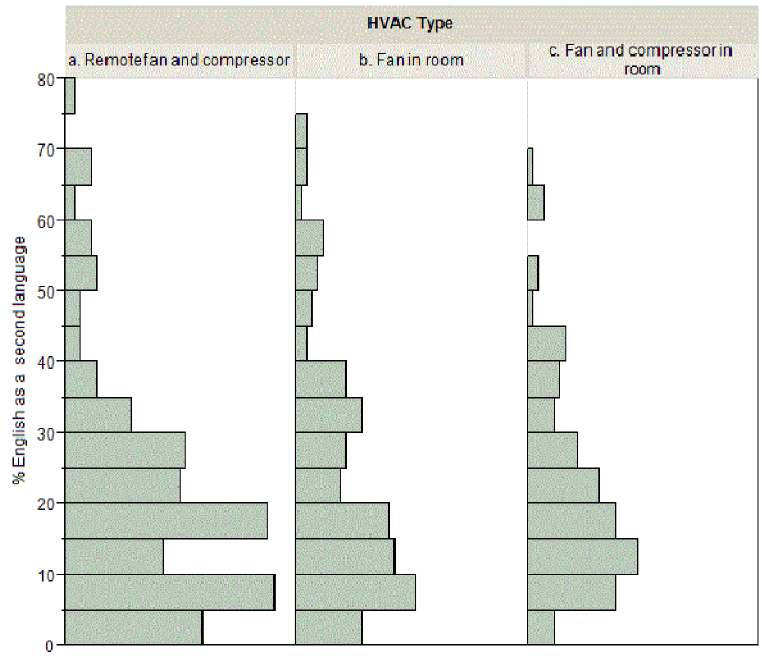


Year Built or Last Renovated

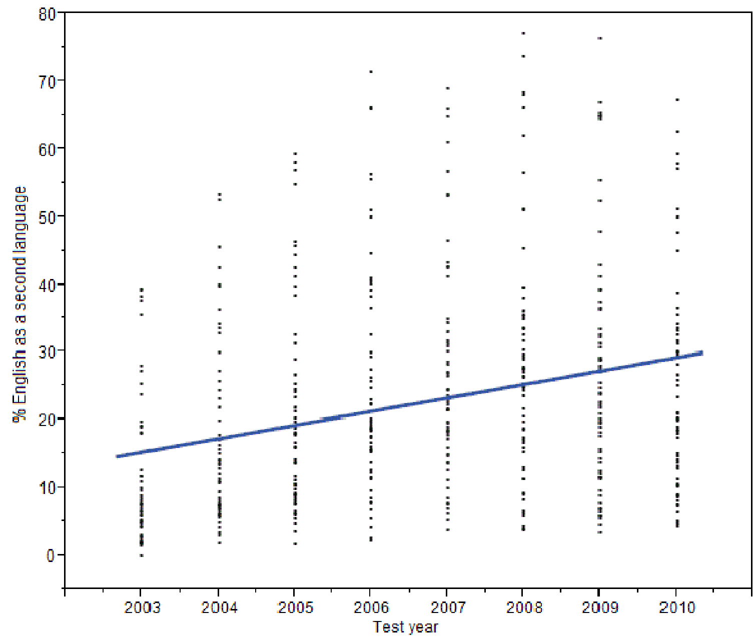




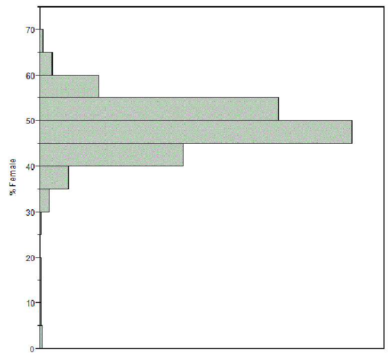
ESL by HVAC type

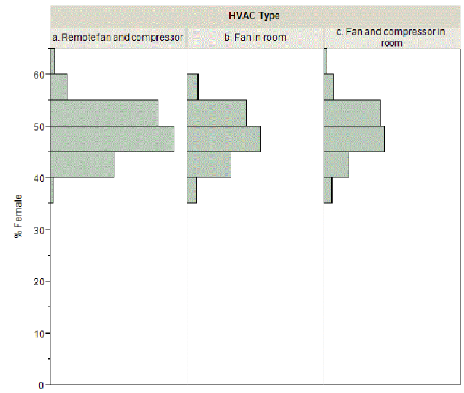


ESL by test year

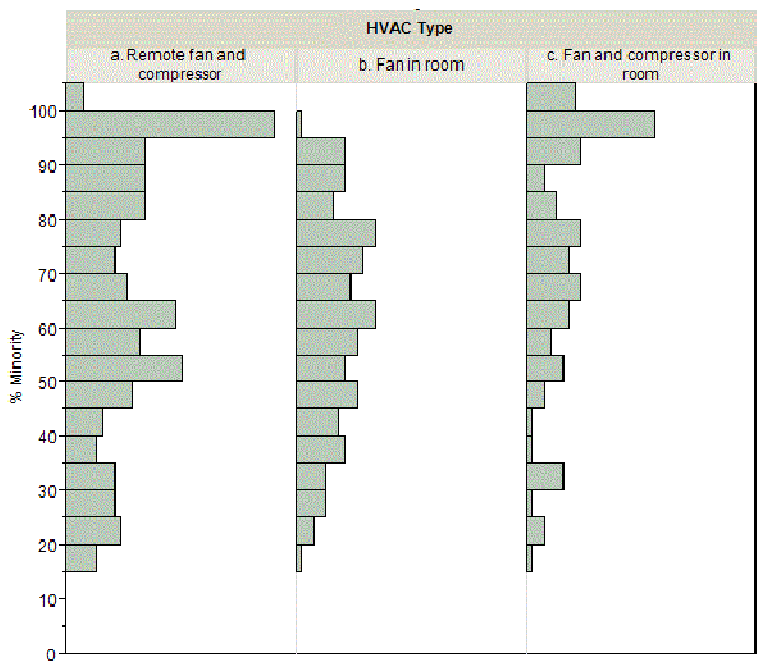


Gender

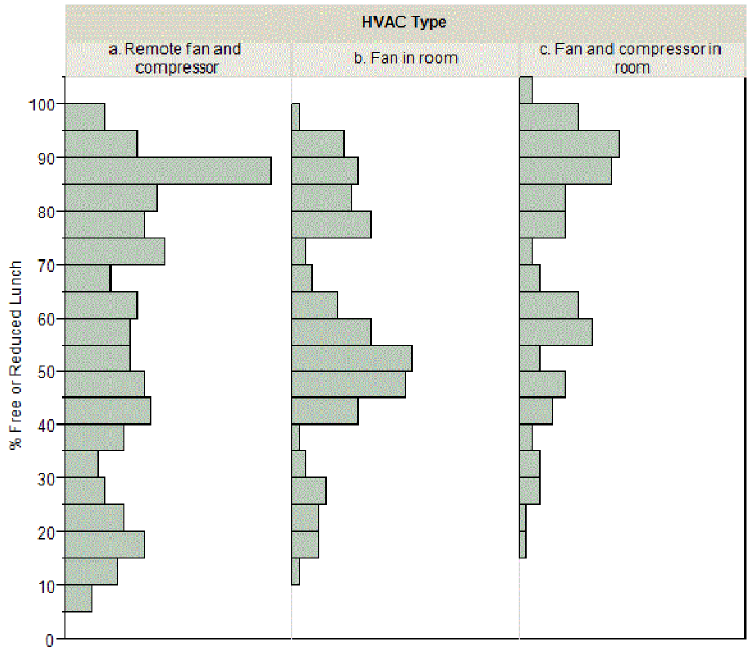




Minority by HVAC type



Socio-economic status by HVAC



APPENDIX E. IRB APPROVAL

VirginiaTech

Office of Research Compliance
Institutional Review Board
2000 Kraft Drive, Suite 2000 (0497)
Blacksburg, VA 24060
540/231-4606 Fax 540/231-0959
email irb@vt.edu
website http://www.irb.vt.edu

MEMORANDUM

DATE: November 6, 2012

TO: Patrick Miller, Ana Maria Jaramillo, Michael G Ermann

FROM: Virginia Tech Institutional Review Board (FWA00000572, expires May 31, 2014)

PROTOCOL TITLE: The link between HVAC and student achievement

IRB NUMBER: **12-897**

Effective November 6, 2012, the Virginia Tech Institution Review Board (IRB) Administrator, Carmen T Green, approved the New Application request for the above-mentioned research protocol.

This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.

Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except where necessary to eliminate apparent immediate hazards to the subjects. Report within 5 business days to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

All investigators (listed above) are required to comply with the researcher requirements outlined at:

http://www.irb.vt.edu/pages/responsibilities.htm

(Please review responsibilities before the commencement of your research.)

PROTOCOL INFORMATION:

Approved As:	**Exempt, under 45 CFR 46.110 category(ies) 2**
Protocol Approval Date:	**November 6, 2012**
Protocol Expiration Date:	**N/A**
Continuing Review Due Date*:	**N/A**

*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.

FEDERALLY FUNDED RESEARCH REQUIREMENTS:

Per federal regulations, 45 CFR 46.103(f), the IRB is required to compare all federally funded grant proposals/work statements to the IRB protocol(s) which cover the human research activities included in the proposal / work statement before funds are released. Note that this requirement does not apply to Exempt and Interim IRB protocols, or grants for which VT is not the primary awardee.

The table on the following page indicates whether grant proposals are related to this IRB protocol, and which of the listed proposals, if any, have been compared to this IRB protocol, if required.

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