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NOISE POLLUTION AND CLASSROOM ACOUSTICS

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EXECUTIVE SUMMARY

Noise pollution has been a growing universal problem affecting people of all ages. As population increases, areas become more crowded; therefore, noise pollution increases due to more noise sources. Noise pollution is a serious issue that negatively effect people in various ways. Recent studies reveal that there are many detrimental outcomes on health and learning processes associated with elevated noise levels. These include, but are not limited to, poor reading comprehension skills, cognitive effects, psychological effects, and speech intelligibility. By reducing noise levels in educational environments, schools may have an overall increase in students' grades. Also, students may receive a better education due to these improved conditions.

Currently, the severity of noise pollution is overlooked in all areas. Due to this lack of awareness of noise pollution, acoustical treatments for classrooms are often overlooked. In tropical areas, such as Puerto Rico, concrete and other forms of masonry are often used for construction. Due to those building materials, poor acoustical conditions can exist. Since most schools are made of those materials, classrooms in Puerto Rico also suffer from poor acoustics.

Our project was developed to provide proof that classroom noise levels in Puerto Rico are excessive and to improve these conditions. We worked in collaboration with Professor Angel David Cruz Baez, the head of the Department of Geography at the University of Puerto Rico at Rio Piedras, to accomplish this overall goal of reducing noise pollution in schools by improving classroom acoustics.

To accomplish these goals we created three objectives for our project. First, we wanted to determine the existing acoustical conditions in Puerto Rico public school

environments. Next, we wanted to improve poor acoustical conditions using recycled material. Lastly, we wanted to determine if there was a market for these acoustical treatments.

After much research, we hypothesized that the local San Juan area classrooms would exceed the acceptable noise levels as predetermined by the American National Standards Institute (ANSI). This project provides significant data supporting this hypothesis.

This project was divided into two main sections: noise level data collection in four local schools and researching recommendations for improving poor acoustical conditions in Puerto Rican public schools. To satisfy the noise data collection, we took noise measurements as described by ANSI standards and noise measurements following our own proposed methods. To further our knowledge of local school conditions, we distributed teacher surveys, teacher questionnaires, and student surveys. After confirming noise pollution was a consistent problem in schools, we were able to begin researching recommendations.

In order to make recommendations, we performed extensive research on existing acoustical treatments. We researched acoustical treatments in order to determine what materials are used in the production of these acoustical treatments. Additionally, we researched the manufacturing process of treatments. To further our knowledge on those treatments, we conducted interviews with an Acoustical Engineer and an Industrial Engineer from the University of Puerto Rico.

After gaining an understanding of acoustical treatments, our group researched recycled materials to determine what exists on the Island that could be used in new acoustical treatments. Along with this research, we conducted an interview with a director from the Authority of Solid Waste to investigate companies collecting recycled materials and the availability of these materials. We developed an innovative method for turning recycled materials that exist on the Island into acoustical treatments for schools and other similarly built buildings. Finally, we performed a cost analysis of these new treatments for marketing purposes.

At the completion of this project, we made low-cost recommendations to improve existing acoustical conditions in Puerto Rico. Since there is consistent use of materials used in construction and there are similar classroom conditions on the Island, these recommendations were extended to apply to all local classrooms. These recommendations, some of which are included below, were created for the schools that we investigated, the Puerto Rico Department of Education, and local companies that are interested in manufacturing acoustical treatments made from recycled material.

During our investigation, we found that the largest source of noise in public schools, disregarding extraordinary circumstances, was from people outside of classrooms. Due to this, we made recommendations to the public schools to designate areas for students to go during their free period. High noise levels from people outside can also be avoided by creating a study period for students rather than a free period. In one of the schools that we visited, we found that construction was a problem. In situations where there is a large noise source nearby, we recommended that when possible classes should be held in areas of the school that are farthest from the noise source. For the public schools, recommendations such as relocating students to different areas of the school where noise is less of a problem were made. These recommendations were changes that could immediately be put into effect at no cost.

Few studies exist concerning noise pollution in Puerto Rico schools. Due to this, we are recommending to the Puerto Rico Department of Education to encourage further studies in this area. Additionally, through collaboration with the Environmental Quality Board and existing sound studies, sound level standards specific to Puerto Rico could be developed. We also feel that schools should educate faculty and students on the severity of the detrimental effects of noise pollution on education. During this educating, people should be encouraged to lower their voices in learning environments when possible.

With our new innovative method for producing acoustical treatments, we are recommending local companies to manufacture these treatments. Since two to three million pounds of recycled material are produced daily in Puerto Rico, we underlined the importance of using this material from the Island. An overhead pricing projection was developed during this project. We highly encouraged companies to consider these prices and the possibility of manufacturing these treatments. These recommendations were for companies that could provide the recycled material and those that would be interested in manufacturing the treatments.

This project could improve classroom acoustics throughout the island of Puerto Rico. Furthermore, it can better the current recycling conditions by reducing the amount of material existing on the island. Not only would these treatments be helpful in improving noise pollution in classrooms, but they could improve conditions in other buildings as well. Lastly, this project can be applied globally to classrooms and buildings located in similar settings and constructed with similar materials to those investigated in our study.

ABSTRACT

Noise is a worldwide problem that has negative effects on health and academic performance. This project, in cooperation with Professor Angel David Cruz Báez from the University of Puerto Rico, evaluated noise levels and sources of noise that were present in San Juan public schools. Through the use of surveys and classroom data collection from four local schools, we determined poor classroom acoustics were problematic in selected schools. From our data and additional research, we made recommendations to local public schools and the Puerto Rico Department of Education for controlling noise distractions in Puerto Rico public school classrooms. Lastly, we made recommendations to companies located in Puerto Rico for producing acoustical treatments from recyclable materials currently existing on the Island.

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CHAPTER ONE: INTRODUCTION

Noise pollution has been a problem for mankind for many years. In the past, this problem has not always been as obvious as it is today. In urban areas, noise pollution has been a severe and growing problem for city residents over the past hundred years (Shapiro, 1993). Sound is measured using decibels on a logarithmic scale, and each decibel increase creates an increase in the noise intensity. For each ten decibel increase in sound, the noise intensity increases by a factor of ten, creating ten times the pressure against one's ear drum (Downey, 2003). This pressure increase means that a ten decibel increase is perceived to be twice as loud by the human ear (Bies & Hansen, 2003).

One cause of the increase of noise in the United States is the steady increase in population over the past few decades. Between 2000 and 2003, the population of the United States increased by 3.3 percent, while the population in metropolitan areas increased by a slightly higher 3.8 percent (Census, 2003). In Puerto Rico, the population has increased from 3,808,603 people in the year 2000 to 3,878,532 people in the year 2003 (U.S. Census Bureau, 2004). This is a 1.8 percent increase during the three year period. Having an increase in population on an island like Puerto Rico also increases the population density because the island is not growing in size.

Additionally, there has been an increase in the number of people living in metropolitan areas, which creates a noisier environment. According to the Census, in the year 2003, the population of the United States was approximately 291,000,000. Of that 291,000,000 people, approximately 241,000,000 people or approximately 83 percent live in metropolitan areas (Census, 2000). The regions with the highest percentage of inhabitants in metropolitan areas are the northeast with 90 percent and the west coast with

90 percent (Census, 2000). Of the nearly 4,000,000 people in Puerto Rico, approximately 95 percent live in metropolitan areas (Census, 2000). Having an increase in population and population density directly affects the noise levels in any given area (Shapiro, 1993). Increased population also causes an increase in school populations.

As populations increase, cities and towns are forced to build new schools in crowded urban areas. Due to schools' locations in urban settings, children suffer a loss in the quality of their education from outdoor noise pollution. From these outdoor distractions, a study of second to fifth graders by Cohen showed that an increase in traffic noise decreased auditory word discrepancy (Evans & Lepore, 2003). The decrease in word discrepancy meant that students were unable to clearly identify spoken words. Additional studies show that children also experience lower test scores and lower overall test performance ratings due to traffic noises (Earthman, 2002). Despite the fact that students partake in many listening activities throughout the school day, it is estimated that various noise distractions, including excessive reverberation, prevent 25 to 30 percent of verbal communication from teachers to be understood (McCarty & Rosen, 2005; Bradley & Sato, 2004). Hearing is important to younger children since they lack automatic auditory cognition closure, a process by which blanks are thoughtfully filled by the listener to understand the speaker's overall message (McCarty & Rosen, 2005).

As seen by the above noise distraction studies, it is clear that children in Puerto Rico are at risk of lower classroom learning comprehension due to noisy school locations and tropical construction methods. Puerto Rico has thirty airports (The World Factbook, 2007); San Juan's Luis Munoz Marin Airport is reported by the FAA to be in the top twelve that affects the largest number of neighbors (Skeleton, 1996). Numerous studies have proven that airport noises are damaging to long-term memory and reading ability of students (Beaman, 2005). Also, a study of 2,010 students ages nine to ten from eighty-nine schools throughout the UK, Spain, and the Netherlands suggested the same results of impaired reading and memory due to noise pollution from car and aircraft noise(Clark et al., 2006). In addition to a high susceptibility to noise, many classrooms and other tropical buildings are highly vulnerable to high reverberation times because of a high use of concrete and other hard materials (Bies & Hansen, 2003). According to the Journal of Wind Engineering and Industrial Aerodynamics (2003), 69.5 percent of commercial buildings are built using either masonry or concrete construction. Since previous studies suggest noise distraction to be detrimental to education, better school acoustical conditions may enhance education and in turn may enhance graduation rates.

According to the Environmental Quality Board of Puerto Rico (2004), noise pollution is an important issue that faces the people of Puerto Rico. The agency has made efforts to collect sound level samples across the island and has already completed sampling in selected areas of San Juan (Backiel; Day; Grouf; Stancioff, 2004). Those sound level samples show that the majority of the noise pollution in Puerto Rico comes from traffic during the day. Since schools are in session during the day, the previous research demonstrates that external noise will be present, although varying, outside of school buildings (Backiel; Day; Grouf; Stancioff, 2004). However, no previous studies in Puerto Rico have measured what the sound levels are like inside the public schools during these hours.

Because no previous studies regarding noise in classrooms have been completed on the island, our sponsor, Professor Angel David Cruz Báez, from the University of

Puerto Rico was interested in a study that dealt specifically with classroom acoustics. Our group and Professor Cruz determined that data from this study would provide important information to the Department of Education regarding the state of classroom acoustics in selected schools. Moreover, the information collected from this study could be used to make recommendations for improving the condition of classroom acoustics in Puerto Rico.

In order to determine the quality of a classroom's acoustic environment for learning purposes, an explicit set of measurement procedures must be followed. The American Speech Language Hearing Association (ASHA, 2005) and The American National Standards Institute (ANSI, 2002) have established that a classroom must be measured using three criteria:

1) The sound level must be measured in an empty classroom.
2) The sound level of the teacher's voice during class must be measured.
3) The reverberation time of the room must be measured.

Since the previous research has been performed outdoors, the sound level measurements can not be used to determine which schools may or may not meet ANSI requirements (ASTM, 2006).

> This report was prepared by members of Worcester Polytechnic Institute Puerto Rico Project Center. The relationship of the Center to the University of Puerto Rico at Rio Piedras and the relevance of the topic to the University of Puerto Rico at Rio Piedras are presented in Appendix A.

Our research was an extension to the previous noise pollution and acoustical studies because the data describes the acoustic conditions inside of schools in addition to outdoor noise (ASTM, 2005). We investigated sound levels and reverberation time by compiling both quantitative and qualitative data through the use of sound measurements, classroom measurements, and teacher surveys. We used our collected data combined with further research and interviews to investigate low-cost solutions for reducing noise and correcting reverberation time. Our main goal of this project was to improve classroom acoustics through the development of a prototype sound reducing panel that is made from recyclable materials and could be manufactured inexpensively.

CHAPTER TWO: BACKGROUND

As we established in Chapter One, one problem in the world today that does not get enough attention is noise pollution. Noise pollution is a growing problem and needs to be dealt with immediately. In this section of the report, we explain why noise pollution is a problem. We also discuss many sources of noise pollution in order to increase awareness on the subject and explain that it does not only come from traffic and industrialized sources. Our group discusses some places in the world that have exceptionally high levels of noise pollution to highlight that it is a problem all over the world. We also discuss the problem of noise in classrooms. Then we define noise pollution in schools and describe current noise levels in school systems. Additionally, we discuss the consequences of noise pollution on learning. We elaborate on these topics to create awareness of the psychological problems noise pollution creates for people and to inform people of the problems many schools have with noise pollution.

In the Background Chapter, we also discuss the history and current states of noise pollution laws in order to demonstrate what needs to be done in the future. Moreover, we elaborate on the importance of conducting proper measurements in an attempt to overcome lack of funding. In addition, we discuss many agencies and laws that are involved in efforts to improve classroom acoustics and show that change is possible but can also be expensive.

NOISE POLLUTION

There are many irritants in this world, one of which is noise pollution. Noise pollution is a problem for many reasons. One reason is that noise levels are much higher than they are supposed to be, as outlined by the American National Standards Institute (ANSI, 2002). High noise levels are a concern because noise pollution has many side effects that many people do not know about. Excessive exposure to noise pollution can lead to annoyance, cause health problems such as hearing loss and excessive anger, and make an area with high noise pollution unappealing (Shapiro, 1993). The amount of noise pollution in the world is increasing, and it is doing so for a few reasons. One reason is because the population of the world is increasing (Shapiro, 1993). Since the amount of land in the world is constant, an increase in population results in an increase in population density. An increase in population density directly affects noise levels (Shapiro, 1993). Another reason is the amount of industrialization is also increasing, which results in an increase in noise pollution (Ruback, 1997).

From Where Does Noise Pollution Come?

Noise pollution can originate from many things. Objects that are used on a daily basis are primary sources of noise pollution. A safe noise level is thirty-five decibels according to the American National Standards Institute (ANSI, 2002). Some of the objects used daily include automobiles, trucks, airplanes, trains, movie theaters, television programs, and sporting events. Almost all of these objects and events create noise levels above the national standard as described below.

City traffic is one important source of noise pollution. In the United States, 241,000,000 people live in metropolitan areas (Census, 2000) and are exposed to constant noise from traffic. City traffic averages approximately eighty decibels (Downey, 2003).

Most of the noise pollution from city traffic comes from cars and trucks in the city, but noise pollution also comes from overhead.

Airplanes are another source of noise that can seriously injure people. A jet engine during takeoff produces noise at levels as high as 140 decibels. Although many people are not exposed to this high noise level for prolonged periods of time, it can still cause harm to their brain as described later in the report. Many airports in the United States have increased in the amount of activity significantly between 1969 and 1994. This increase in activity brings about an increase in noise pollution. The airports with the most change in activity are Dallas/ Fort Worth with a 100 percent increase in the level of noise, Las Vegas with a 52 percent increase, Atlanta with a 41 percent increase, Detroit with a 37 percent increase, and Boston with a 35 percent increase (Skelton, 1996). Some other cities that have highly populated areas surrounding the airports include New York with 194,972 residents, Miami with 163,234 people, Chicago O'Hare with 93,860 people, Atlanta with 81,621 people, and Chicago Midway with 79,960 residents. All of the people included above are exposed to an average noise level of at least sixty-five decibels (Skelton, 1996). All-in-all, there has been an increase in the levels of noise in many cities throughout the United States caused by air travel.

Almost everyone in the United States owns a television set. It has been reported that 98 percent of American homes own a television and children spend an average of 2.5 hours a day watching television (Coon, 2002). These 2.5 hours spent watching television are a lot of time to be exposed to noise pollution each day. Television creates noise pollution because television sets, although they may not be thought to cause much noise pollution, actually release sixty-eight decibels of sound when turned to an average volume (Downey, 2003). This amount of exposure to high levels of noise from television is not healthy for a human brain, especially for prolonged periods of time repeated daily.

Television sets are not the only household products that create excessive levels of volume. More household products that produce high noise levels include vacuum cleaners producing 75 decibels, stove fans creating 84 decibels, dishwashers generating 88 decibels, headphones making 110 decibels (Downey, 2003), and many electric drills generating 95 decibels (Havas, 2006). It is important that people are informed that noise pollution comes from many household products, such as a vacuum cleaner or dishwasher, so that they can reduce their risk of being affected by high levels of noise.

Noise is a World Problem

There are countries all over the world with noise levels above an acceptable decibel level. There are many European countries where the noise levels are intolerable. According to the Organization for Economic Cooperation and Development, Greece is the noisiest country in Europe (Time International, 1998). In Athens, 60 percent of the population is exposed to noise levels above seventy-five decibels. This level is much higher than the acceptable level set by the American National Standards Institute. Athens is not the only place in the world with high levels of noise pollution.

Many other Europeans are exposed to unhealthy noise levels. According to the European Environment Agency, approximately 65 percent of Europe is exposed to noise levels exceeding fifty-five decibels on a regular basis (Time International, 1998). This level of noise is high enough to cause many irritations such as sleep deprivation. The European Environment Agency also collected data that showed that almost 113,000,000 people in Europe are exposed to more than sixty-five decibels of sound, and another 10,000,000 people are exposed to levels exceeding seventy-five decibels. These high levels of noise can cause a loss of hearing and may induce high levels of stress in many people.

Asia also has noise pollution problems. A case study was done in Bangkok to evaluate noise levels in different traffic zones. During the study, it was established that the noise levels during the day ranged from seventy-three to eighty-three decibels (Leong, 2003). In the same area, the noise levels were also measured at night and were evaluated to range from sixty to seventy-five decibels (Leong, 2003). These daily noise levels were measured to be higher than an acceptable intensity.

Another continent that experiences high noise levels is Australia. A case study was done in Brisbane to model different levels of noise pollution. It was found that many buildings in Brisbane are exposed to noise levels that are very high. Over four hundred buildings in the Brisbane area that are along main roads are exposed to levels of noise in excess of seventy decibels (Brown, 2002). Additionally, over nine hundred buildings are exposed to noise levels exceeding sixty-five decibels (Brown, 2002). Brisbane is a major city in Australia and many of its buildings are affected by high noise levels. These are just a few examples of places with high levels of noise pollution.

Noise Problems in Puerto Rico

Like many places in the world, Puerto Rico is also affected by noise pollution. The population of Puerto Rico has been growing steadily for many years. There was an 8.1 percent increase in the population of Puerto Rico between 1990 and 2000 (Census, 2000). The majority of people that live in Puerto Rico live in metropolitan areas. This means there is a greater chance that they are exposed to higher levels of noise pollution (Census, 2000). Puerto Rico is not exempt from noise pollution because it is a small island. Noise pollution is a problem in Puerto Rico just as it is a problem in many other places in the world.

Noise pollution is a problem throughout the island of Puerto Rico, especially in the San Juan area. Measurements were taken by a previous Worcester Polytechnic Institute student group (Day, 2004), and they showed that many places in the Santurce area, a coastal area in San Juan, had readings of noise levels above seventy decibels. The same group also performed sound tests in other areas such as the northern Rio Piedras (an area just south of San Juan). In that area, most of the noise came from local traffic and some came from passing airplanes (Day, 2004). The loudest area recorded by that group was a shipyard because of the constant truck and machine movement. The shipyard previously described averaged sound levels over eighty decibels (Day, 2004). As shown, noise pollution has been found to be exceeding acceptable noise levels in some places in Puerto Rico.

Effects of Tropical Construction on Noise Control

The previous section has demonstrated that Puerto Rico is susceptible to environmental noise pollution due to the Island's high population density. However, Puerto Rico's high population density is not the only contributing factor to poor classroom and indoor acoustics. According to J. Rocafort, an esteemed Acoustical Engineer and Architect at the University of Puerto Rico, the types of construction methods that are necessary for tropical environments create a very poor acoustical environment (personal communication, March 15, 2007).

Tropical construction practices are used to make buildings practical and durable for tropical environments. Buildings in tropical regions are designed to use natural ventilation and shaded areas to keep building interiors cool (Department of Defense, 2006). Designers often replace glass windows with aluminum shutters to promote circulation when air conditioning is too costly to consider. The fact that many tropical buildings are open to the air also means that they are open to noises that are present outdoors (STC Ratings, 2004).

Additionally, buildings in tropical regions are usually built with concrete or masonry in order to make them resilient to mold, moisture, insects, salt-laden air, earthquakes, and tropical storms. In fact, Khandri and Morrow (2003) claimed that 70 percent of commercial buildings in Puerto Rico were built using re-enforced concrete or masonry. Unfortunately, concrete and masonry are extremely reflective surfaces to sound waves that are traveling throughout a room (Bies & Hansen, 2003). As a result, many rooms in tropical environments have problems with high reverberation times, or echoes that interfere with speech and listening (J. Rocafort, personal communication, March 15, 2007).

NOISE IN CLASSROOMS

With roughly 73,200,000 Americans currently attending school, (US Census Bureau, 2006) space for both building construction and classroom capacity is clearly an issue. Over the last twenty years, National Center for Educational Statistics (NCES) surveys revealed Hispanic school enrollment has increased by 20 percent. These standing enrollment trends seem to suggest that school enrollment will continue to increase in the future. In Puerto Rico alone, there are 1,558 public schools spanning over only 8,870 square kilometers of land area. Additionally, there are also 25,735 kilometers of roadways running throughout the Island (School-Tree, 2007). Due to land limitation from roadways and existing buildings, schools are built closer to one another and closer to high traffic areas.

In addition to poor locations affecting noise pollution levels, some schools are not effectively built to ideally accommodate acoustical needs. In past surveys, the NCES established that teachers and students rated 18 percent of schools nationwide as acoustically unsatisfactory. Studies conducted throughout the world in both urban and rural settings show that empty classrooms average between forty-five to forty-eight decibels when acoustically untreated (Drockwell & Shield, 2003). Once people are factored into classrooms, the same studies found that noise levels with silent students rise to an average of fifty-six decibels (Drockwell & Shield, 2003). With small interactions among students, an average of seventy-two decibels is reached (Drockwell & Shield, 2003). These findings suggest that classrooms that are not acoustically treated reach high noise levels.

What Are the Sources of Noise in Classrooms?

According to Bies and Hanson (2003), evaluating the different sources of noise in a classroom is an essential part of analyzing the room's acoustical performance. Noise that is found in classrooms can be described as background noise. Bradley and Picard (1997), the U.S. Access Board (2003), and ANSI (2002) claim that problematic background noise can originate in the forms of, but are not limited to, traffic and construction noise, mechanical noise such as noise generated by an air conditioner, talking and yelling, and noise from moving chairs and desks. Regardless of where the noise in classroom comes from, a variety of authors agree that background noise is a problem that needs to be addressed (ANSI, 2002; ASHA, 2005; ASTM, 2006; Bradley & Picard, 2000; Bronzcraft, 2002; United States Acess Board, 2003). However, it is the array of possible sound sources that make one definitive and final solution to poor classroom acoustics impossible (ANSI, 2002; STC Ratings, 2004).

Simply addressing background noise may not cover all the acoustical concerns in a classroom setting (Bradley & Picard, 2000). Excessive background noise can be a characteristic of poor acoustics, but poor acoustics do not necessarily mean that excessive background noise is present (ASHA, 2005). In addition to background noise, various authors agree that the incorrect reverberation time in a classroom is a problem (ANSI, 2002; ASHA, 2005; Bies & Colin, 2003; Johnson, 2000). The reverberation time in a classroom is a measurement of the time required for a sound level to deteriorate sixty decibels. Simply put, the reverberation time is a measure of how long a single sound will be present in a room before it is absorbed (Bies & Hansen, 2003). If a classroom does not have the optimal reverberation time, as described by ANSI, then the noises in the room will continually reflect off of surfaces and disrupt teacher-student communication (Johnson, 2000).

Effects of Excessive Noise in Classrooms

Studies suggest that in order for a person to be effectively heard, they must be speaking at a level fifteen decibels louder than background noise (Beaman, 2005). Due to urban settings, outside noises can prevent students inside classrooms from effectively hearing their teachers. One study showed that only 70 to 75 percent of communication is audible in classrooms due to noise pollution (McCarty & Rosen, 2005). This rate can be devastating to a student's understanding of material. Noise distractions affect students since young children have not fully developed automatic auditory-cognitive closure, the ability to fill in missing words (McCarty & Rosen, 2005). Due to this incomplete process, students will misunderstand an overall message and may fall behind in class while trying to figure out what was said moments earlier.

Moreover, many phonological tests proved to be negatively affected by surrounding noises (Schick at al, 2000). With increased background noises, studies by Klatte and Hellbruk have shown significant disruptive effects on various tasks such as recalling spoken words and numbers (Schick et al, 2000). Further studies of learning disruption by incoherent background speech also support negative effects on phonological tasks (Beaman, 2005). As suggested by these studies, more background noises will also lower listening test scores.

Noise Effects on Reading Comprehension

Almost all studies considering noise pollution as a source of distraction monitor reading comprehension levels. One study testing a New York school that was located near train tracks found that children closer to the noise tended to score lower on reading comprehension than students farther from the noise. After rubber padding was added to the train tracks in order to lower noise, students' reading scores improved. Additionally, students on the noisy side scored equally with those that were once on the quiet side (Earthman, 2002). Another study showed that noise from cars caused slower recall of information in students including prose recall (Beaman, 2005). With reading being such an important aspect of education, controlling noise may help better students' educations.

Cognitive Effects of Noise

For various reasons, an assortment of aspects of learning abilities can be greatly affected by noise. List recall studies suggest that forgotten words are due to different functions of working memory and long-term memory (Conway & Engel, 1994). Words at the end of a list are more easily recalled due to their existence in primary memory or current contents in the conscience. Since words in the primary memory are still in the mind, they are easy to retrieve while beginning words that should be encoded are interrupted by surrounding noises and forgotten (Craik et al, 2000).

Additionally, other cognitive processes such as concentration can be affected by noise. Cognitive coping theory suggests that due to constant elevated noise distractions, children learn to tune out noises (Drockwell & Shield, 2003). Although this seems beneficial to keep students focused on their work, students have a hard time distinguishing between important information and distracting noises. This can lead to the tuning out of important information and lower concentration (Drockwell & Shield, 2003). Furthermore, increased noise may over stimulate children. The Arousal Hypothesis suggests that increments of noise increase arousal; therefore, noise stimulates students in an educational environment keeping them more alert and increasing performance (Hygge, 2003). Although this seems true for a small percentage of students, it appears continual noise arousal greatly impairs concentration (Drockwell & Shield, 2003).

Psychological Effects of Noise

Although few studies have been conducted on psychological stress aspects, recent studies clearly show that noise can cause psychological effects among students. Evans & Lepore (1993) revealed elevated levels of blood pressure in students attending school near chronic noise sources. When taken away from the noise source, it took a long time for students' blood pressure to decrease. In those areas located very close to large noise sources such as airports, decibel levels reached as high as 95 to 125 (Evans & Matthews, 2006). From chronic exposure to high decibel levels, students may be at risk for high blood pressure due to these constantly elevated blood pressure levels (Evans & Matthews, 2006).

Lack of motivation also appears to be caused by psychological stresses from noise. Evan and Lepore (1993) have demonstrated that outside noise sources decrease students' motivation and create temporary feelings of helplessness in students. This Evan and Lepore study found that students attending schools close to major airports were more likely to give up on simple puzzle tasks. Further research from this study showed that teachers found it harder to create motivation in these students due to a lower tolerance of frustration than most other students. Also, a study by Evans & Matthews (2006) showed that students were more passive due to feelings of helplessness that were caused by frustration from being unable to complete simple tasks. For example, students would ask their teachers to make choices for them such as picking out a prize for completing tasks (Evans & Matthews, 2006).

Not only are students affected by these stressors, but teachers are also affected. Several of the same studies conducted on students exposed to airplane and traffic noises also monitored the teachers and showed the same effects as seen in students (Beaman, 2005). After classroom audio enhancements were made, one study showed there were 25 percent fewer absences among teachers (McCarty & Rosen, 2005). Although this behavior may have been due to being observed as suggested by the Hawthorne Effect (Vandersluis, 2005), here the McCarthy and Rosen study argued that decreased absences were due to decreased noise. Without constant primary teacher attendance, students have substitute teachers and miss whole lesson plans. Also, Shapiro (1991) revealed noise can increase anxiety and lower one's desire to help others. If teachers feel the stress of this noise, they may in fact not teach to the best of their ability.

NOISE LAWS

The ultimate goal of this project is to invoke changes that will lead to better acoustics and a better learning environment in Puerto Rico's public schools. These changes will have to be put into effect by the Department of Education as a whole or by individual schools that accept that there is a problem with noise in classrooms. This section will briefly discuss the previous and current policies on noise pollution in order to explore how noise is addressed by governing bodies in the United States. In addition, this section will show that previous policies and laws do not recognize classrooms as specific problem areas.

History of Noise Laws

In the history of noise laws in the United States, there are two noise control acts that demonstrate the United States Federal Government's concern with noise pollution. These two acts are the Noise Control Act of 1972 and the Quiet Communities Act of 1978 (Backiel; Day; Grouf; Stancioff, 2004). Both acts were proposed and developed by the Office of Noise Abatement and Control, a sub-division of the Environmental Protection Agency. The Noise Control Act of 1972 declared that all citizens in the United States should be entitled to an environment free of noise that affects their health and well-being (Bureau of National Affairs, 1996). The act declared that the federal government was responsible for establishing federal noise standards that would be followed by state and local governments. The Quiet Communities Act enabled local and state governments to receive grants and funding for noise abatement purposes through the Environmental Protection Agency (Bronzaft, 1998). These acts were supervised and enforced by the Office of Noise Control and Abatement. However, President Reagan shut the office down in 1982, and the responsibility for enforcing and developing noise regulations was transferred to state and local governments. The closing of the office also meant the termination of Environmental Protection Agency funds for noise abatement. Local and State governments would have to find funding for noise policies from other organizations (EPA, 2007).

In the past ten years, there have been multiple attempts to resurrect the Office of Noise Control and Abatement because the re-opening of the office would demonstrate that the government was still concerned with noise pollution (Bronzcraft, 1998). Two bills called the Quiet Community Act of 1997 and the Quiet Community Act of 2003 were proposed but were rejected because previous noise studies lacked credibility.

Noise Laws for Classrooms

Today, noise laws that exist at a state or local level govern noises that exist outdoors in different zones. Many of these state laws are enforced by noise complaint systems with a set of guidelines defining when and why a complaint can be filed (Law Library, 1997). However, there are no laws that regulate what noise levels should be inside of a classroom setting (ASHA, 2005). Different organizations such as American National Standards Institute (2005) and the American Speech Language Hearing Association (2005) have developed standards for school acoustics. Their guidelines are only applied if a school district selects to follow them. They are not required by any legislation. However, some school districts are fighting to pass laws that make these guidelines a requirement for all new construction (Inside: Acoustics, 2006).

Advocates for a Change

The problem with noise regulations and laws, in addition to incomplete sound data and outdated legislation, is that insufficient government funding exists to make changes happen (Bronzaft, 1998). The history of noise laws in the United States demonstrates that the government has consistently chosen other issues to fund. However, the President of the United States has requested for $54,400,000,000 in discretional appropriations for the fiscal year of 2007 (Department of Education, 2007). Although the $54,400,000,000 set aside in 2007 is 5.5 percent lower than in 2006, the

2007 appropriations have grown 29 percent since 2001 (Department of Education, 2007). This funding can be granted to schools or school districts that propose a school improvement or demonstrate a need to the Department of Education. In addition, the President requested specifically that $200,000,000, an increase from 2006, should be set aside for Title 1, school improvement, grants. Recently, President Bush has proposed an increase in Title 1 funding to $536,500,000 for the fiscal year 2008. The U.S. Department of Education of Education Budget Services (2007) claims that the increase in school improvement grants will be instrumental in helping Puerto Rico improve the conditions of the Island's public schools. Also, the President has called for $746,100,000 for Puerto Rico for 2008 to help the Commonwealth's students achieve proficiency in reading and math (U.S. Department of Education Budget Services, 2007). This information shows that money exists for improvement if school systems recognize noise is an existing problem that hinders a student's ability to learn.

What needs to be done?

Organizations such as ASTM and ANSI have developed and agreed upon standard methods for analyzing classroom acoustics. The use of a standard procedure is very important for the advancement of legislature and improvements on classroom acoustics because the collected data can be compiled and analyzed in order to present a strong case (ASTM, 2006). These measurement procedures can then be used to pinpoint the problem areas of each classroom (ASHA, 2005). However, Bronzcraft (2002) claims that while the simple act of compiling data may provide enough information to address a single classroom or school, data collection alone will not pass laws. The study also maintains that school systems need to educate the parents of the children, their faculty, and local government officials about the effects of poor classroom acoustics.

Who is forging the way?

There are many organizations that are forging the way for better school acoustics. Some organizations such as the ANSI and the ASHA are urging school districts to adopt their agreed upon acoustical standards (ANSI, 2002; ASHA, 2005). Other organizations such as the Acoustical Society of America, the National Council of Acoustic Consultants, Noise Pollution Cleaning House, No Noise Organization, and the Quiet Classrooms Organization are educating teachers and the public about the detrimental effects that excessive noise has on a student's ability to learn and are praising the guidelines that are suggested by ANSI and ASHA (United States Access Board, 2003; Inside: Acoustics, 2006; Law Library, 1997; Bradley & Picard, 1997). The efforts of the organizations listed above have not gone unnoticed since there are multiple school districts who have implemented the ANSI standards. In fact, the Minnesota Education Senate Committee has already approved a bill that will require all new classrooms constructed in Minnesota to be built according to the 2005 ANSI standards for classroom acoustics (Inside: Acoustics, 2006). Also, the state of Connecticut passed a law in 2005 that requires all classrooms in new or renovated school buildings to comply with the ANSI standards (News Flash, 2005).

CHANGE CAN BE EXPENSIVE

Due to the expensive cost of most acoustical treatments, in many cases it is not feasible for schools to be treated with commercially available materials. Recently, Puerto Rico suffered an estimated $740,000,000 deficit in public funds during the 2005-2006 school year (Rivera, 2007). The Puerto Rico Department of Education experienced an estimated $364,000,000 loss due to this deficit (Government Development Bank for Puerto Rico, 2006). Although Congress recently increased the federal education budget in Puerto Rico, the effects of such a large deficit will take several years to overcome (U.S. Department of Education, 2007).

One investigation of eight schools near the St. Louis National Airport suggested each school would cost from $253,000 to $500,000 to be acoustically treated (Schweiker, Wentz, & Taylor, 1995). Also, according to Acoustical Society of America, it would cost five thousand dollars for one typical high school classroom to be correctly treated (Bloomberg, 2002). Prices for ceiling tiles can range from four to ten dollars per square foot (Acoustic Product Division, 2007). Wall tiles are also expensive and depending on the material the tiles are constructed from, they cost approximately three to four dollars per square foot (The Supply Stores, 2007 & Audio Advisor, 2007). At such high costs to upgrade acoustical treatments, the existing Department of Education budget could not provide enough money to treat many local schools.

CHAPTER THREE: METHODOLOGY

The most important goal of this project was to assess the noise problems facing public schools in Puerto Rico. There was a need for extensive data regarding classroom acoustics because previous studies had not been conducted or were left incomplete. Based on our research, we hypothesized that a high percentage of Puerto Rican public schools exceeded the recommended background noise levels based on previous outdoor noise studies and the Island's large urban population. However, with no pre-existing acoustical classroom data that supported this hypothesis, the claim was a mute point. For that reason, this project provided valid acoustical measurements that were used to determine if local classrooms were in compliance with ANSI standards. Our data, combined with previous sound level studies in Puerto Rico, was an assessment that provided important information used to create recommendations to improve existing acoustical conditions in Puerto Rican public schools.

SCHOOL SELECTION & PERMISSION

First and foremost, in order to obtain noise measurements from Puerto Rican schools, there needed to be a method in which the schools themselves were selected. Since we had limited time and limited measurement resources for the scope of this project, our group and sponsor chose to measure public schools located only in the San Juan metropolitan area. The Department of Education supplied us with a list of eight public schools that they would allow us to visit. Three of these schools were located in San Juan and the fourth was located in Guaynabo. We decided that four schools would offer sufficient findings for our project since we concluded, based on our interview with

Jorge Rocafort, that the acoustical environment in schools would be very consistent in San Juan (J. Rocafort, personal communication, April 24, 2007).

Secondly, we went through a process of acquiring permits from the Puerto Rico Department of Education for entering the schools to conduct our investigation. In order to obtain permission, we needed to send a completed copy of our overall proposal. Also, we needed to create letters to teachers and school directors that would briefly explain who we are, our project, and the methodology we would be following at the schools. Lastly, we needed to send a step-by-step version of our methodology to the Department. Ultimately, we were able to gain permission to enter the four schools that we selected.

SCHOOL DATA COLLECTION

To prepare for our school measurements, we visited all of the selected schools to set up dates for our visitations. On the arranged date at each selected school, we arrived at 10:00 a.m. Upon arriving, our group measured the school's physical and acoustical characteristics in multiple ways. We first took outdoor observations (See Appendix D) from 10:00 a.m. to 10:30 a.m. These observations were non-invasive and included photographs of the building, building sketches, note-taking, and dimension measurements. From 10:30 a.m. to 11:00 a.m., we took outdoor noise measurements around the school and noted which areas were the noisiest (See Appendix F). Also, we performed outdoor sound level measurements using an A-weighted time averaging sound level meter in accordance with ASTM 2006 standards (ASTM, 2006). Those readings provided the average noise levels that surrounded the school at the noisiest part of the day according to previous studies (Backiel; Day; Grouf; Stancioff, 2004). This data determined which classrooms were at risk from external noise sources.

Then, from 11:00 a.m. to 11:30 a.m., we took indoor observations (See Appendix E) which were also non-invasive. While walking around the halls of the school, our group made several different observations. The purpose of these observations was to determine which areas of the school were susceptible to noise. Our group was looking for ventilation systems, pipes, windows, and mechanical devices and noting the location of classrooms in relation to noise sources. From 11:30 a.m. to 12:00 p.m., our group took indoor noise measurements by walking around the halls using our sound level meter and determining which areas were the loudest.

The next step of our evaluation included a comparison of our indoor and outdoor observations. Our group determined which classrooms were exposed to the most noise both internally and externally and which classrooms were exposed to the least noise. With the help of several faculty members from the University of Puerto Rico and from each visited school, we selected two classrooms in which to take acoustic measurements. The first classroom was chosen in an area found to be surrounded by the most noise both internally and externally, while the second classroom was in an area surrounded by the least noise. Our group took our sound level measurements in one classroom from each area depending on the availability of the rooms.

Following our selection of the classrooms, we took acoustical measurements and observations in the selected classrooms (See Appendices G & E). The observations listed in Appendix E were performed briefly in order to determine where to start sound measurements.

Next, the team conducted indoor acoustical measurements in two ways (See Appendix G) described below for details of the method. These measurements were completed once for each school.

The first method was to measure classroom acoustics in an empty classroom that had no activity in any of its adjacent rooms. Our group measured the A-weighted sound level in the loudest classroom from 12:00 p.m. to 12:30 p.m., in accordance with ANSI standards during the noisiest part of the day. From 12:30 p.m. to 1:00 p.m., we recorded the sound levels in the quietest classroom in the same manner.

The second method, as proposed by our group, took A-weighted sound level measurements in empty classrooms during the noisiest part of the day and while at least one adjacent classroom and hallway were occupied. The second method served to demonstrate what noise sources were not accounted for by ANSI but were present since the existing classrooms were not built to comply with ANSI standards. Our group took these measurements from 1:00 p.m. to 1:30 p.m. for the loudest classroom, and 1:30 p.m. to 2:00 p.m. for the quieter classroom.

In one school, we noticed the use of air conditionings in some classrooms. In order to see if this affected noise levels, we took additional measurements immediately following our other noise measurements. These measurements were taken in the unoccupied classroom while adjacent classrooms were also unoccupied. They were recorded in the same manner as our other measurements; however, there was one recording with the air conditioning on and another with the air conditioning unit off.

In addition to taking sound measurements, we estimated the reverberation time of each classroom according to ANSI, 2002 (See Appendix B). This method determined if the classroom met standardized acoustical performance criteria (ANSI, 2002). Our group performed measurements from 2:00 p.m. to 3:00 p.m. in the two classrooms that we measured for sound. The measurements include classroom dimensions, classroom object (desks, chairs, file cabinets, etc.) dimensions, and classroom object material. These measurements were used to calculate the reverberation time in that classroom.

Since teachers were able to provide us with important information on daily classroom noises, we distributed an anonymous survey to forty-five randomly selected teachers at each school (See Appendix H). Additionally, we distributed thirty-five free response surveys (See Appendix J) to the teachers in our previously selected classrooms. These surveys were distributed at the time of our noise measurements and were collected when the schools completed them. From these questions, we were able to determine if teachers believed that decreasing noise levels would increase the quality of class time. Also, we were able to obtain data that enabled us to determine which schools were most affected by noise. This survey method allowed teachers to provide us with their opinion. This information was useful when we were developing specific recommendations for decreasing noise.

SCHOOL DATA ANALYSIS

Once the sound measurements and surveys had been collected from each school, they were recorded and entered by our group into Microsoft Excel and Statistical Package for Social Sciences (SPSS) respectively. Through the use of Excel, we were able to plot the sound level data on a set of time series plots for each measurement taken. The average sound level measurements that were computed by our group for each reading were the L_{eq} readings (See Appendix B). Next, we computed the three-term moving average for each set of classroom sound measurements and plotted them on one graph for each school. Those graphs enabled us to compare the effect that different classroom locations and conditions had on sound levels within each school.

To further analyze our data, we used the Chi Square test, the T-test, and the A-nova test in order analyze the differences between the school results We entered each variable from our survey into SPSS so that our survey data could be directly recorded in the program. We grouped surveys from each school together but we did not distinguish between classrooms within schools since the surveys were anonymously distributed. Next, we created graphs and tables that summarized the responses of the surveys and the results of the statistical analysis. Those tables and figures allowed us to compare results among schools and between classrooms.

ACOUSTICAL TREATMENT RESEARCH

After sound measurements were taken and the data was analyzed, we performed in-depth research. Our group investigated several possibilities of current acoustical treatments that are used to reduce reverberation time in order to prepare us for making recommendations. First, we investigated existing treatments that are currently being used worldwide. We also researched the cost of these treatments. After understanding what solutions currently exist, we considered using other methods and materials that could be feasible for improving classroom acoustics. Through research concerning abundant recyclable materials on the island, we developed several recommendations for use of that material. Following this research, we investigated the costs of the custom machinery that would be required to manufacture our acoustical treatments. Also, we investigated the cost of buying the recycled materials and providing the labor that would be required to operate the machinery. From all of our research, we were able to develop a price comparison between our proposed recycled products and the products that existed in the commercial market. We developed an overhead pricing that would allow us to determine cost of recyclable material and machines necessary to produce acoustical tiles. Our group focused mainly on the cost of the machinery and the raw materials, and we estimated a minimum and maximum price per tile that would generate income for a company in their first year of manufacturing the material. With this pricing estimate, we were able to contact several companies on the island to investigate the possibility of a future market for acoustical treatments made of recycled material.

In order to further our research and evaluate the feasibility of our recommendations, we interviewed three professionals in different fields (See Appendix N). First, we interviewed Jorge Rocafort, an acoustical engineer from the University of Puerto Rico, in order to confirm that our methodology would provide valid measurements. Next, we interviewed Antonio Rios, a National Recycling Coalition Executive, to further determine which recyclable materials existed on the island and in what quantity materials were discarded. Lastly, we interviewed Dr. Sergio Caporali, an Industrial Engineer at the University of Puerto Rico. Since he is currently performing a noise study of multiple occupations in Puerto Rico, he was able to provide us with important information regarding noise and reverberation time that concurred with our findings. From all of these interviews, we were able to further our understanding of noise pollution and feasible recommendations that would result in better acoustical conditions for local Puerto Rican schools.

CHAPTER FOUR: RESULTS AND ANALYSIS

The main goal of our project was to assess the acoustical conditions in Puerto Rican public schools and to compare our findings to the ANSI, 2002 classroom acoustic standards. This chapter reports and evaluates our group's findings regarding each school's physical description and location, sound level measurements, reverberation estimates, and responses to the student and teacher surveys. In addition, this chapter discusses those findings that will help improve acoustics on the island through the use of recyclable material. The reader should note that both the results and the analysis of the results are included together in this chapter. Our group decided that comparing and analyzing the results among schools was much more effective with the analysis directly following each finding. Lastly, the use of graphs and tables in this section is limited to include only findings that were directly relevant to the discussion in each section. More detailed results were listed in the appendices of the report.

GENERAL SCHOOL DESCRIPTIONS

Listed below are descriptions of each school that we visited. The descriptions give details of the area that surrounds each school. This section also describes the location of the school that we determined to produce the most noise pollution.

Rafael Martínez Nadal

This school is located just off of a main road. In the front part of the school, there is a frequently-used road that had a high traffic rate. On that side of the school, there is also a vendor selling snacks and drinks that attracts many of the students during the day.

On one side of the school, there is a small area with trees and a building that was providing little to no noise pollution. Behind the school, there is a bus station, approximately sixty yards away. The bus station is set back far enough to not affect the noise levels at the school. Located on the last side of the school is a courtyard from which there is little noise pollution. We observed that most of the noise comes from the street on the front side of the building from passing cars and gathering students.

Dr. Cesáreo Rosa Nieves

This school is located on the outskirts of a residential area. In the front of the school, there is a parking lot and an inactive construction site that does not provide any noise pollution. On one side of the school, there is an active construction site that produced a great deal of noise pollution. There is constant noise from jackhammers and construction vehicles throughout the day. Behind the school, there is an elementary school set very far away. There is also a basketball court located behind the school. On the last side of the school, there is housing that did not produce any noise pollution. We determined that most of the noise pollution comes from the construction site that ran the length of one side of the school.

Sabana Llana

This school is located very close to a high traffic road and a traffic light. The front of the school is approximately thirty feet from a street with frequent traffic. On the front side, there is a vendor that attracted many people. On one side of the school, there is housing that did not provide much noise pollution. Behind the school, there is a courtyard with a basketball court to which many students are attracted to throughout the day. On the last side of the school, there is a parking lot for faculty members, along with another building. The areas of the school subjected to the most noise pollution are the front because of the high traffic street and the courtyard.

República Del Perú

This school is located on a main road. The front of the school is located next to a street with frequent traffic from buses and trucks. On one side of the school, there is another street that is used often. Across that street, there is a residential area. Behind the school, there is a basketball court that is used frequently by the students. On the last side of the school, there is another residential area. Most of the noise pollution at this school comes from the traffic on the front side of the school from the frequent buses and trucks passing by.

SOUND LEVEL MEASUREMENTS

This section described the sound levels that our group found in each classroom at each school. Each school that we visited had its own heading under which all of our findings for that school were described. The last heading in this section was used to describe the statistical trends that our group found in all four schools.

Rafael Martínez Nadal (RMN)

We determined that room one at the Rafael Martínez Nadal school is located in the section of the building that is the noisiest. Room two is located in the section of the building that we determined is the quietest. Our group took sound level measurements in each classroom while there were students in the adjacent classrooms and while students were not. The terms unoccupied and occupied refer to whether or not students were located in adjacent classrooms. During an "unoccupied reading" there were no students in any rooms that were adjacent to the classroom that we were measuring. During an "occupied reading" there were students in the adjacent classrooms and hallways that surrounded the classroom that we were measuring. It is important to note that there were no students in any of the classrooms that we measured during the time we were taking sound level readings.

Table 1 shows the results of each sound level measurement method for both classrooms.

Table 1. Rafael Martínez Nadal Table of Average Sound Level Measurements

Rafael Martínez Nadal Table of Average Sound Level Measurements (dBA)

	Avg. Reading 1	Avg. Reading 2	Avg. Reading 3	Avg. Reading 4	Avg. Reading 5	Avg. Reading 6	Total Average
Room 1 (Unoccupied)	61.35	61.12	58.35	62.65	59.73	59.03	**60.37**
Room 1 (occupied)	55.72	58.34	58.95	57.84	58.05	58.25	**57.86**
Room 2 (Unoccupied)	56.78	55.89	57.32	56.39	56.91	57.23	**56.75**
Room 2 (occupied)	55.72	58.34	58.95	57.84	58.05	58.25	**57.86**

The average readings that are listed on the top row of the chart correspond to the average of the ten reading that we took in each thirty second measurement interval. These readings are the best measure of what the noise was like while the sound levels were being recorded. The total average column on the right represents the overall noise level in each room during the measurement period.

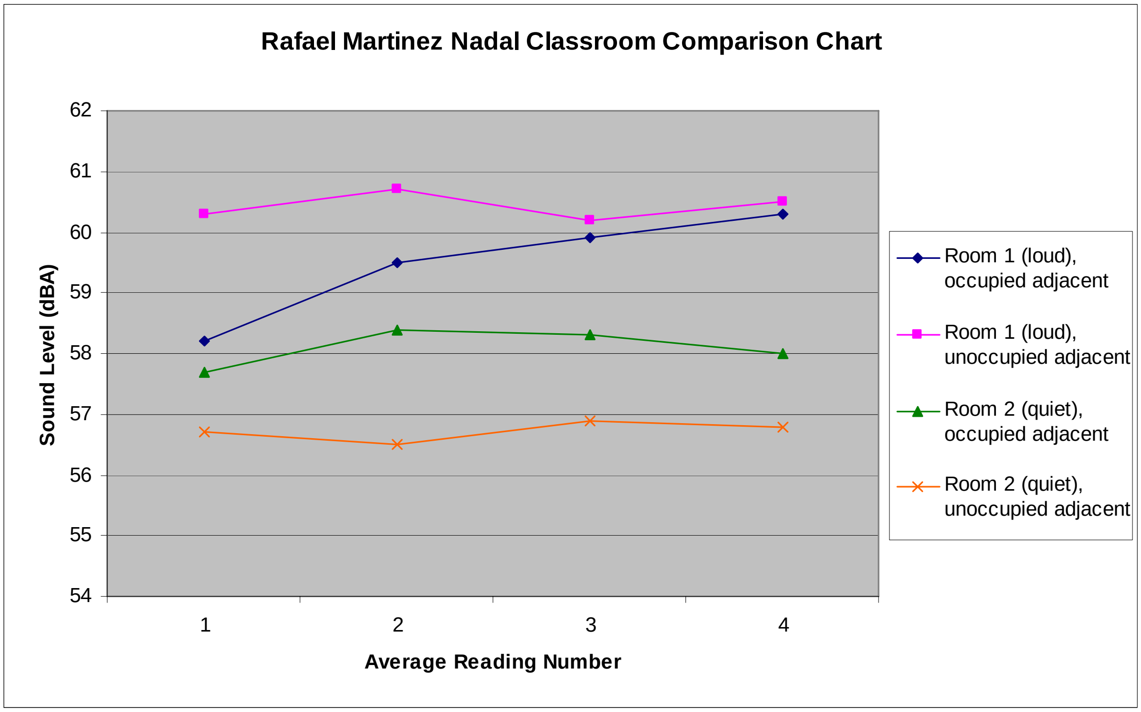

Figure 1. Rafael Martínez Nadal Classroom Comparison Chart

Figure 1 shows the three-term moving average of the sound level readings that our group recorded. The three-term moving average was taken from the results of Table 1 and was used to show steadiness in each set of readings.

Analysis of the Results

The most important aspect of our sound level measurement study was the total average sound level that we recorded in each classroom. According to ANSI, 2002, if the total average of each classroom exceeds the recommended level of thirty-five A-weighted decibels on average by more than three decibels, then that classroom is not in compliance with the ANSI standards. As seen in Table 1 and Figure 1, the total average sound levels in each classroom were nearly double the thirty-five decibel recommendation.

Additionally, both tables demonstrate that both the loud and quiet areas of the school are not in compliance with the standards.

So what caused these classrooms to have noise levels in excess of thirty-five decibels? According to our observations, there were multiple sources of noise that contributed to the overall noise levels in our measurements. First, the school is constantly surrounded by noises from the street that is located in the front of the school. We observed sounds originating from passing cars, buses, trucks, pedestrians, birds, and from residents who lived across the street from the school. Additionally, the rear of the school is adjacent to a bus depot where buses leave and enter throughout the day. However, while these noises contributed to the overall background levels that we observed, they caused very few increases to the base sound level of approximately fifty-seven decibels on average. We observed that the most frequent increases in sound levels were when people were shouting from outside of the classroom. These disturbances were sometimes caused by pedestrians and residents who were outside the school. However, the majority of the yelling originated from students who were outside of the classrooms.

The second important aspect of our sound study was to determine if there is a significant difference between unoccupied and occupied classrooms. Table 2 below shows the results of a T-test that compares the mean values of the unoccupied and occupied classrooms at the Rafael Martínez Nadal School.

Table 2. T-Test Between Unoccupied and Occupied Classrooms at Rafael Martínez Nadal

	Paired Differences					t	df	Sig. (2-tailed)
	Mean Difference	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
1 RMN loud unoccupied - RMN loud occupied	1.33500	2.09894	.85689	-.86770	3.53770	1.558	5	.180
2 RMN quiet unoccupied - RMN quiet occupied	-1.10500	1.17468	.47956	-2.33775	.12775	-2.304	5	.069

Result number one is the comparison between the unoccupied and occupied readings in room one and result number two is the comparison between the unoccupied and occupied readings in room two. The results of the T-test in Table 2 show that there is no statistically significant difference between unoccupied and occupied conditions in the classrooms. The reason that there is no significant difference in noise level between unoccupied and occupied classrooms is because the main source of noise, yelling, was present in both readings. Our group took the unoccupied readings when there were no students in any of the adjacent classrooms. However, students were still present in the school's courtyards and people were still present in the street in front of the school.

The third important aspect of our sound study was to determine if there is a significant difference between the loud and quiet sections of the school. Table 3 below shows the results of a T-test that compares the mean values between the loud and quiet classroom sound level measurements.

Table 3. T-Test Between Loud and Quiet Classrooms at Rafael Martínez Nadal

	Paired Differences					t	df	Sig. (2-tailed)
	Mean Difference	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
1 RMN loud unoccupied - RMN quiet unoccupied	3.78500	2.24416	.91618	1.42989	6.14011	4.131	5	.009
2 RMN loud occupied - RMN quiet occupied	1.34500	2.43444	.99386	-1.20979	3.89979	1.353	5	.234

Result number one is the comparison between the highest and lowest average sound levels in the unoccupied rooms and result number two is the comparison between the highest and lowest average sound levels in the occupied rooms. The results of the T-test show that there is a statistically significant difference between the average sound levels in the loud and quiet unoccupied classrooms. However, the results of the T-test between the loud and quiet occupied classrooms show that there is no statistically significant difference between the loud and quiet occupied classrooms.

Our group expected to find a statistically significant difference in the noise levels between the loud and quiet classrooms because our preliminary noise readings suggested that the sound levels were about five decibels on average less in the quieter section of the school. The result of the unoccupied room T-tests are consistent with our expectations because the amount of disturbances during the sound level readings was comparable. Both the loud unoccupied and quiet unoccupied readings were interrupted by approximately six loud yells. However, the sound level measurements that were taken in the quiet occupied room were interrupted approximately fourteen times by multiple sources of sound such as a car alarm, music playing from a car stereo, and multiple yells from students outside the classroom. The sound level measurements from the loud occupied room were only interrupted by yells that were consistent among all of the readings. Since these measurements were not recorded under consistent conditions, they can not be used to draw conclusions based on the result of the T-test.

Dr. Cesáreo Rosa Nieves (CRN)

We determined that room one at the Dr. Cesáreo Rosa Nieves School was in the noisiest area of the school, and was therefore our noisy classroom measurements. Room two was determined to be in the quietest area of the school so it was used for our quiet measurements. We took the measurements using the methods described in our methodology having the first three measurements taken at the seated level and the second three at standing level. The results are in Table 4 below.

Table 4. Dr. Cesáreo Rosa Nieves Table of Average Sound Level Measurements

Dr. Cesáreo Rosa Nieves Table of Average Sound Level Measurements (dBA)

	Avg. Reading 1	Avg. Reading 2	Avg. Reading 3	Avg. Reading 4	Avg. Reading 5	Avg. Reading 6	Total Average
Room 1 (Unoccupied)	57.38	59.49	63.82	59.98	59.41	61.61	**60.29**
Room 1 (occupied)	63.07	62.11	64.06	62.94	63.78	64.99	**63.41**
Room 2 (Unoccupied)	52.44	52.20	54.78	51.48	52.85	52.50	**52.71**
Room 2 (occupied)	58.65	56.71	58.68	60.25	65.93	63.16	**60.56**

Each average reading is the average of the ten measurements taken over a thirty second time interval. The measurements taken were the best representation of the noise level in each classroom situation. The right-most column contains the average noise level of each classroom.

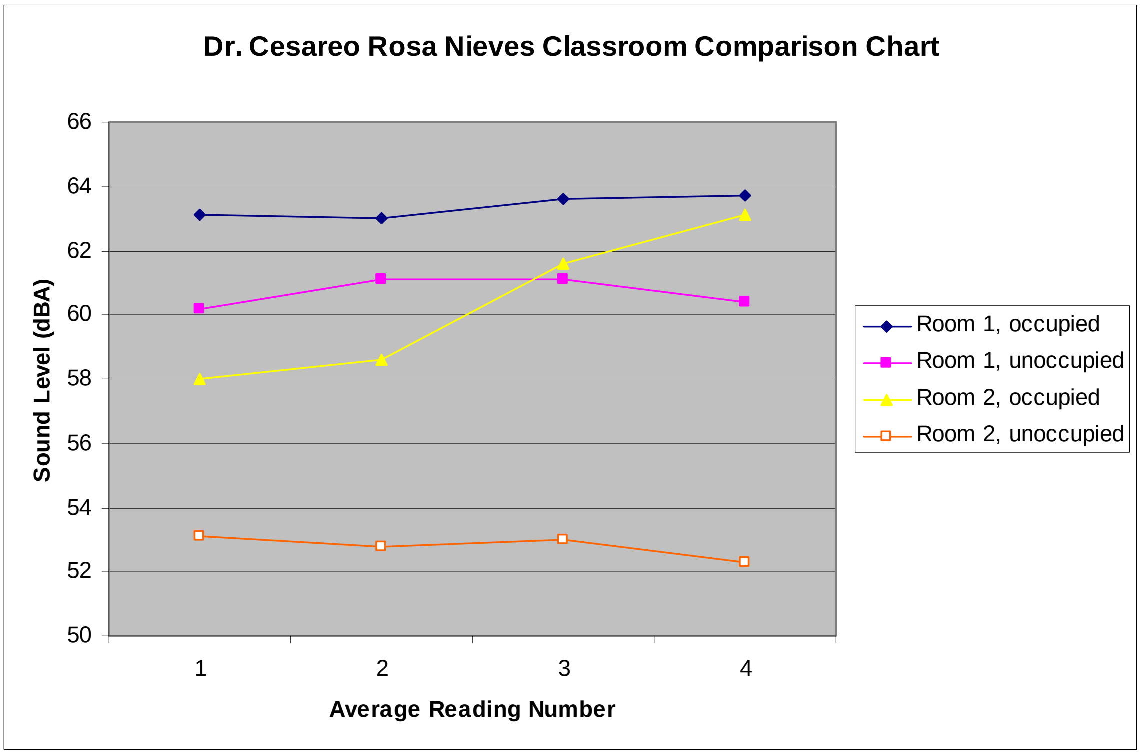

Figure 2. Dr. Cesáreo Rosa Nieves Classroom Comparison Chart

Figure 2 shows the three-term moving average of the sound levels we recorded. The three-term moving average was taken from the results of Table 4 and was used to show steadiness in each set of readings.

Analysis of the Results

As shown in Table 4 and Figure 2, the average noise levels in both classrooms at the Dr. Cesáreo Rosa Nieves School exceeded ANSI standards. These results also show that the loudest and quietest sections of the school do not conform to the standards.

There are many reasons for the high noise levels at the Dr. Cesáreo Rosa Nieves School. First, at this school there is a construction site that is located fifty-five feet away from one side of the building. In this construction site there are jackhammers, construction vehicles, cranes, trucks, and constant activity throughout the entire day. The construction site created noise levels in excess of sixty decibels during our measurements. On the other three sides of the school, there are courtyards. Although most of the noise came from the construction site, some of the noise came from human interaction surrounding the school. Sometimes the noise was from pedestrians walking by the school, but most of the noise from humans was from the students yelling in other classrooms, the hallways, or the courtyards. There was also minimal noise pollution from cars passing by the school because there are no streets in close proximity of the school.

For the Dr. Cesáreo Rosa Nieves School, we also performed T-tests to compare the difference between the noise levels in the when the adjacent classrooms and hallways were occupied and unoccupied. Table 5 below shows the results of a T- test comparing the mean values of the unoccupied and occupied classrooms at the Dr. Cesáreo Rosa Nieves School.

Table 5. T-Test Between Unoccupied and Occupied Classrooms at Dr. Cesáreo Rosa Nieves

	Paired Differences					t	df	Sig. (2-tailed)
	Mean Difference	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
1 CRN loud unoccupied - CRN loud occupied	-3.11667	1.83452	.74894	-5.04188	-1.19146	-4.161	5	.009
2 CRN quiet unoccupied - CRN quiet occupied	-7.85167	3.62428	1.47961	-11.65512	-4.04822	-5.307	5	.003

Result number one is the comparison between the loud unoccupied and loud occupied classrooms and result number two is the comparison between the quiet unoccupied and quiet occupied classrooms. Table 5 shows that there is a statistically significant difference between the sound levels in the loud unoccupied and loud occupied classrooms as well as between the quiet unoccupied and quiet occupied classrooms.

At time when we took sound level measurements when adjacent rooms were occupied, there were multiple increases in the sound level that were due to students who yelled in the courtyard. These interruptions occurred during regular class time and were the main source of noise that caused the sound level readings to increase above their basal level. However, during the time we took the sound level measurements when adjacent rooms were unoccupied, the students were at lunch and there were very few people in the courtyard and hallways of the building. Our sound measurements during this period were influenced by the same noise levels from the construction site outside of the building; however, our sound level measurements taken when adjacent rooms were unoccupied were not affected by student yells. The absence of student yells was enough to decrease the average sound level by approximately three decibels in the loud classroom and by approximately eight decibels in the quiet classroom (See Table 4).

The next step of our analysis was to determine whether or not classroom location within a school made a significant difference on the classroom's average noise levels. Table 6 below shows the results of a T-test that compare the means between the loud and quiet classrooms.

Table 6. T-Test Between Loud and Quiet Classrooms at Cesáreo Rosa Nieves

	Paired Differences					t	df	Sig. (2-tailed)
	Mean Difference	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
1 CRN loud unoccupied - CRN quiet unoccupied	7.58000	1.64998	.67360	5.84845	9.31155	11.253	5	.000
2 CRN loud occupied - CRN quiet occupied	2.84500	2.92247	1.19309	-.22194	5.91194	2.385	5	.063

Result number one describes the difference in means between the loud unoccupied and quiet unoccupied classrooms and result number two describes the difference in means between the loud occupied and quiet occupied classroom sound measurements. Table 5 shows that there is a statistically significant difference between the average sound levels in the loud, unoccupied and the quiet, unoccupied classrooms. However, the results of Table 5 show that there is not a statistically significant difference between the mean noise levels in the loud occupied and quiet occupied classrooms.

In a similar manner to the Rafael Martínez Nadal School, the difference between the loud and noisy sections of the school was only significant when students were not in the hallways of the building or in adjacent classrooms. Both average sound levels in the unoccupied classrooms were affected only by the amount of outdoor noises that propagated into the classrooms and not by people within the building. Therefore, these results demonstrate that there were sections of the Cesáreo Rosa Nieves School that were subjected to less noise from exterior noise sources such as the construction.

During the occupied readings, the multiple interruptions from students yelling in both of the classrooms caused the sound levels to rise and as a result produced a mean difference that was not significant. These results were not influenced by outdoor noise sources since the interior noises were much louder.

Sabana Llana (SL)

Once again, we determined that room one at Sabana Llana was located in the noisiest area of the school. Room two was in the quietest area of the school. Again, the measurements were taken according to the methods described in our methodology. The results are in Table 7 below.

Table 7. Sabana Llana Table of Average Sound Level Measurements

Sabana Llana Table of Average Sound Level Measurements (dB A)

	Avg. Reading 1	Avg. Reading 2	Avg. Reading 3	Avg. Reading 4	Avg. Reading 5	Avg. Reading 6	Total Average
Room 1 (Unoccupied with AC off)	48.89	51.41	49.70	53.23	49.91	52.55	**50.95**
Room 1 (occupied with AC off)	58.64	56.66	56.81	58.81	58.06	56.16	**57.19**
Room 1 (occupied with AC on)	64.84	64.61	64.34	64.70	64.56	64.15	**64.53**
Room 2 (Unoccupied)	56.05	58.62	55.69	58.69	58.14	56.59	**57.25**
Room 2 (occupied)	60.25	63.06	64.39	63.41	62.50	62.99	**62.77**

Each average reading is the average of the ten measurements taken over a thirty second time interval. These measurements best represent the noise level in each classroom situation. The right-most column contains the average noise level of each classroom. For this classroom we took an extra measurement because we wanted to see the affects on noise levels with the air conditioner on.

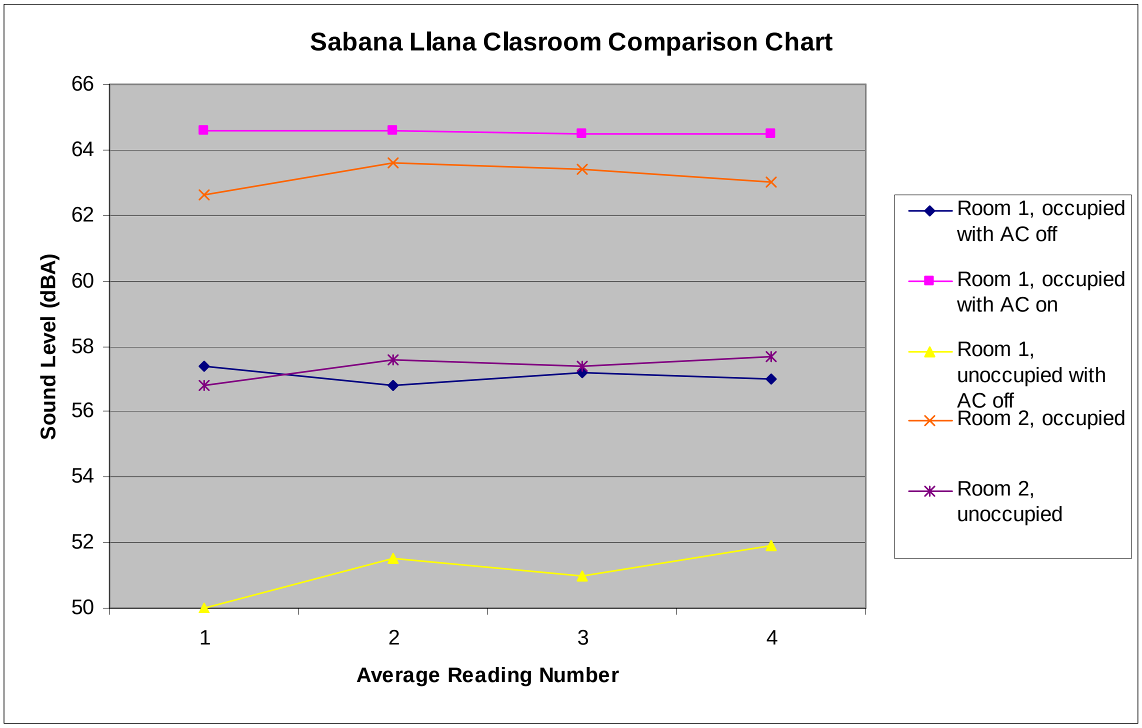

Figure 3. Sabana Llana Classroom Comparison Chart

Figure 3 shows the three-term moving average of the recorded sound levels. The three-term moving average was taken from the results of Table 7 and was used to show steadiness in each set of readings.

Analysis of the Results

Like in previously reported schools, the average noise levels in both classrooms at the Sabana Llana School exceeded ANSI standards. These results also show that the loudest and quietest sections of the school did not conform to the standards and show that the air conditioner increased noise levels.

There are many reasons for the high noise levels at the Sabana Llana School. First, this school is located thirty feet from a street on one side. There was a lot of traffic on this street because it is located very near to a traffic light. There were cars and trucks driving by all day. The street did produce a lot of noise pollution, but the main source of noise pollution at Sabana Llana, like in the other schools, is the students. Throughout the day, there were students yelling and screaming in the courtyard. Additionally, there is a basketball court located in the courtyard where the students played basketball, kicked soccer balls, and played other games. The main source of noise at this school was undoubtedly the students yelling and playing games.

For the Sabana Llana School, we again performed T-tests so that we could compare the difference in noise level between the occupied and unoccupied classrooms. Table 8 below showed the results of a T-test comparing the mean values of the unoccupied and occupied classrooms at the Sabana Llana School.

Table 8. T-Test Between Unoccupied and Occupied Classrooms at Sabana Llana

	Paired Differences					t	df	Sig. (2-tailed)
	Mean Difference	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
1 SL loud unoccupied - SL loud occupied	-5.51667	1.75565	.71674	-7.35911	-3.67423	-7.697	5	.001
2 SL quiet unoccupied - SL quiet occupied	-6.40833	2.56135	1.04567	-9.09631	-3.72036	-6.128	5	.002

The first result is the comparison between the loud unoccupied and loud occupied classrooms. The second is the comparison between the quiet unoccupied and quiet occupied classrooms. The results from Table 8 show that there is a statistically significant difference between the noise levels in the loud unoccupied and loud occupied classrooms as well as between the quiet unoccupied and quiet occupied classrooms.

While we were recording the sound level measurements in both classrooms, there were several increases in the sound level due to students playing basketball and yelling in the courtyard and hallways. These occurrences happened during class time and were the main source of noise that caused our sound readings to increase. When we recorded data for the classroom readings while all of the adjacent rooms were unoccupied, the students were not in close proximity with the classrooms. This resulted in lower noise readings because most of the sound was coming from the students out in the courtyard or on the basketball court. With the lack of student activity, the sound level decreased by approximately seven decibels in one classroom and five decibels in the other classroom (See Table 7).

We investigated potential relationships between where the classrooms were located and noise levels. Table 9 below shows the results of a T-test that compares the loud and quiet classroom.

Table 9. T-Test Between Loud and Quiet Classrooms at Sabana Llana

	Paired Differences					t	df	Sig. (2-tailed)
	Mean Difference	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
1 SL loud unoccupied- SL quiet unoccupied	6.53333	1.41425	.57737	5.04917	8.01750	11.316	5	.000
2 SL loud occupied – SL quiet occupied	5.64167	2.45830	1.00359	3.06184	8.22149	5.621	5	.002

The first result describes the difference in means between the loud unoccupied and quiet unoccupied classroom sound level measurements and the second result describes the difference in means between the loud occupied and quiet occupied classroom sound level measurements. The results from Table 9 show that there is a statistically significant difference between the average sound levels in the loud unoccupied and the quiet unoccupied classrooms as well as between the mean noise levels in the loud occupied and quiet occupied classrooms.

We had expected to find and did find that classroom location would affect the sound level. In our sound level data we determined that there was approximately a five to seven decibel difference between the two classrooms. Both locations were interrupted many times by outside noise sources. Each classroom was interrupted by the students playing in the courtyard.

República Del Perú (RDP)

We visited three classrooms at the República Del Perú School. Room one was located in the noisiest area of the school. Room two and room three were located in the quieter sections of the school. The measurements were taken according to our methodology and are represented in Table 10 below.

Table 10. República Del Perú Average Sound Level Measurements

República Del Perú Table of Average Sound Level Measurements (dB A)

	Avg. Reading 1	Avg. Reading 2	Avg. Reading 3	Avg. Reading 4	Avg. Reading 5	Avg. Reading 6	Total Average
Room 1 (Unoccupied with AC off)	55.12	59.58	53.50	55.86	51.58	53.86	**54.91**
Room 1 (Unoccupied with AC on)	58.77	57.00	57.87	58.37	57.46	56.33	**57.63**
Room 2 (occupied)	57.86	63.67	62.68	64.30	60.38	64.24	**62.19**
Room 2 (Unoccupied)	66.32	62.48	67.53	62.56	62.56	62.19	**63.27**
Room 2 (Unoccupied with fans on)	64.28	65.24	65.31	64.57	65.93	66.64	**65.33**
Room 3 (occupied)	57.80	56.54	56.32	53.87	56.30	57.60	**56.41**

Each average reading is the result of the average of the ten measurements taken in a thirty second time span. We took extra measurements with fans on for room two in order to establish what effect the fans had on the noise levels. The results of Table 10 show that the difference in noise levels with and without fans on was not significant because the background noise levels were also high. However, if the background noise levels had been lower, then the difference would have been much larger. We also chose to measure a third room at this school because it was located in a different building of the school.

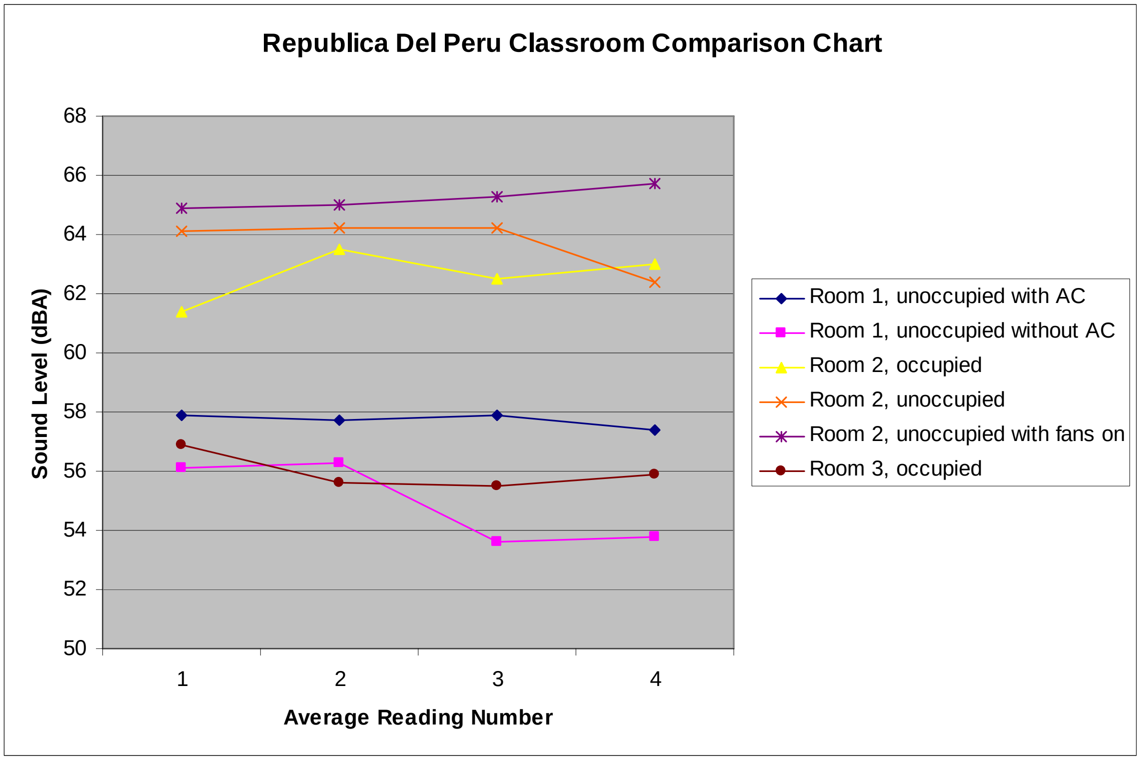

Figure 4. República Del Perú Classroom Comparison Chart

Figure 4 shows the three-term moving average of the recorded sound levels. The three-term moving average was taken from the results of Table 10 and was used to show steadiness in each set of readings.

Analysis of the Results

Each of the measured classrooms at the República Del Perú school exceeded the ANSI standard of thirty-five decibels on average as shown in Table 10 and Figure 4. The results show that all areas of the school exceeded the standards.

From our observations, we were able to determine reasons for the high noise levels at the República Del Perú school. One main source of noise pollution comes from the frequency of buses traveling along the road that is thirty feet from one side of the school. This road also had other constant traffic throughout the day. On average, twenty cars or trucks passed by every minute and many of them were playing loud music. Other sources of noise pollution included a basketball court on one side of the school. Many students gathered at this basketball court and cheer each other on which results in high noise pollution. Additionally, airplanes flew over this school regularly and produced high levels of noise. For this particular school, the main source of noise pollution was the high volume of traffic on the main road in front of the school.

Like at the other schools, we performed T-tests on our data to compare the difference in noise level between the occupied and unoccupied classroom sound level measurements. Table 11 compared the mean values of the noise in unoccupied and occupied classrooms at the República Del Perú School. We recorded unoccupied and occupied sound level data in one of the classrooms because there was only one classroom available to perform sound measurements. For the second classroom, we performed the sound level measurements with the air conditioner on and with the air conditioner off. This only gave us T-test results for one classroom.

Table 11. T-Test Between Unoccupied and Occupied Classrooms at República Del Perú

	Paired Differences					t	df	Sig. (2-tailed)
	Mean Difference	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
1 RDP loud unoccupied - RDP loud occupied	-2.05500	2.29124	.93540	-4.45951	.34951	-2.197	5	.079

The first result is the comparison between the sound level measurements that were taken with empty adjacent classrooms and with occupied adjacent classrooms. The results from Table 11 statistically show that there is not a significant difference between the sound levels in the loud unoccupied and loud occupied classrooms.

During our sound level measurements in the first two classrooms, there was a lot of noise from the road in the front of the building. Many buses and trucks drove by the school creating high levels of noise. These incidents happened throughout the day everyday.

Table 12 below shows the results of a T-test that compares the loud and quiet unoccupied classrooms.

Table 12. T-Test Between Loud and Quiet Classrooms at República Del Perú

	Paired Differences					T	df	Sig. (2-tailed)
	Mean Difference	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
1 RDP loud unoc - RDP quiet unoc	8.92333	1.39239	.56844	7.46211	10.38456	15.698	5	.000

This result describes the difference in means between the loud unoccupied and quiet unoccupied classrooms sound level measurements. The results from Table 12 show that there is a statistically significant difference between the average sound levels in the loud unoccupied and the quiet unoccupied classroom sound level measurements.

We expected to find that the classroom location would directly affect the sound level. From our sound measurements, we determined that there was approximately a nine decibel difference between the two different locations within the school. Both locations were interrupted multiple times by outside noise sources such as buses and other traffic from the nearby street.

REVERBERATION TIMES

This section describes the reverberation times that our group calculated in each classroom at each school. Reverberation time is defined as the time it takes for the sound level in a room to dissipate sixty decibels. Below, we compare all the schools in two different scenarios. The first scenario is with the windows opened, and the second is with the windows closed. Our results indicate that by opening the windows reverberation is greatly lowered.

At each school we visited, we took measurements so that we could calculate the reverberation time. The standard set by the ANSI suggests that the reverberation time for schools should be approximately .6 seconds. The graph below shows the reverberation time for each classroom at each school that we visited.

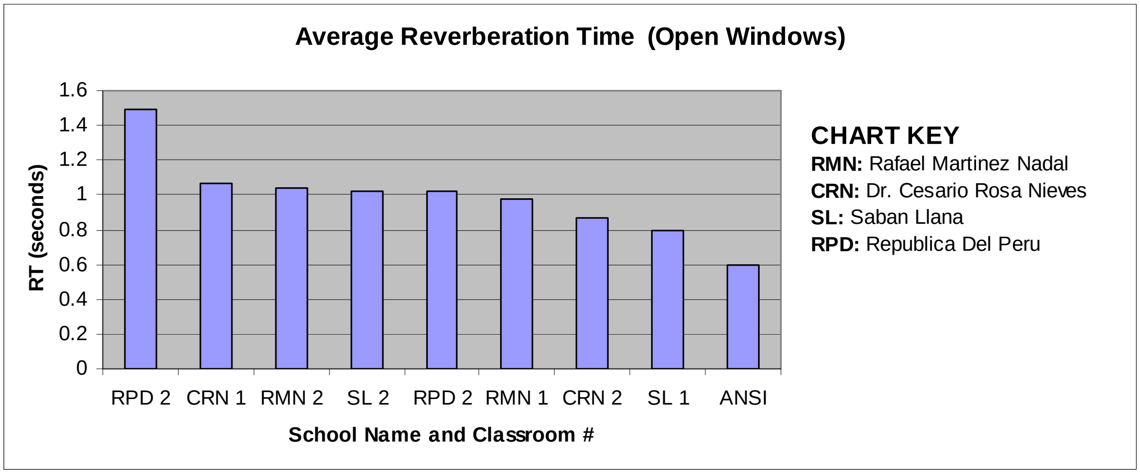

Figure 5. Average Reverberation Time (Open Windows)

As shown in Figure 5, with the windows opened, every school where we took noise measurements exceeded the ANSI suggested standards. There was one classroom that has more than double the reverberation time set by the ANSI. Of the other classrooms, four classrooms had reverberation times greater than one second.

The following figure shows the reverberation time for each classroom with the windows closed.

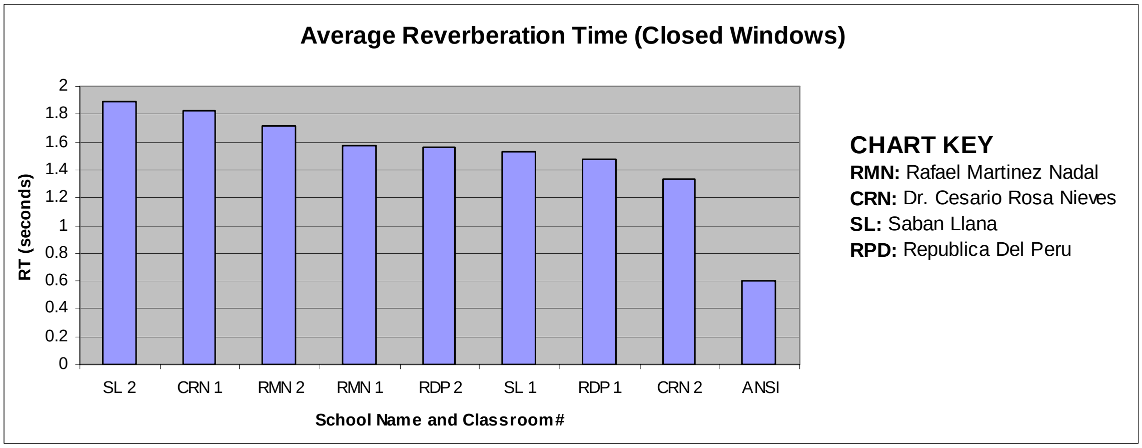

Figure 6. Average Reverberation Time (Closed Windows)

With the windows of the classrooms closed, the reverberation times were much higher than acceptable by the ANSI. Every classroom had a reverberation time that was more than double of what is suggested by the ANSI, and a few of the classrooms were even three times higher than suggested. As shown in Figure 5 and Figure 6, reverberation times are much more acceptable when the windows of the classroom are opened. Regardless, in both cases the reverberation time was higher than acceptable and needed to be reduced.

TEACHER SURVEYS

This main purpose of this section was to present the data that our group collected from the teacher surveys. Since the teachers were in the classroom everyday, they were able to provide us with important information about how they perceive the sound levels in their classroom on a daily basis. In addition, the teacher surveys offered a basis of comparison to the literature that we reviewed on the detrimental effects that poor acoustics has on learning. Also, the results of the teacher survey provided an additional method in which to verify that our sound level data accurately reflected the noise levels in the schools on a given day. For our study, we were able to collect forty-five teacher surveys that we used in our analysis of the survey results.

Question Number 1

The purpose of Question Number 1 was to understand the different grades that the teachers in the four schools taught. The teachers at all of our schools taught a range of students from seventh to tenth grade. We did not find any statistically significant differences in survey responses depending on the grade, since many teachers taught more than one grade. Due to the fact that there were so few definitive answers to question number one, the results of the Chi-Square test could not be used to test for statistical significance.

Question Number 2

The purpose of the second teacher survey question was to ask the teachers if they heard noises from outside of their classroom during class hours. Table 13 shows how the teachers from all four schools responded to the question "While you are in your classroom, can you hear noise from outside of the building?" Table 14 shows the results of the Chi-Square test that describe the variance between the schools' responses.

Table 13. Teacher Survey Question Number 2

CRN: Dr Cesáreo Rosa Nieves RDP: República del Perú RMN: Rafael Martínez Nadal SL: Sabana Llana			**Are there noises outside of the class during class hours?**		Total
			n/a	yes	
School Name	CRN	Count	0	19	19
		% within School Number	.0%	100.0%	100.0%
	RDP	Count	0	13	13
		% within School Number	.0%	100.0%	100.0%
	RMN	Count	0	7	7
		% within School Number	.0%	100.0%	100.0%
	SL	Count	1	5	6
		% within School Number	16.7%	83.3%	100.0%
Total		Count	1	44	45
		% within School Number	2.7%	97.8%	100.0%

Table 14. Chi-Square Test for Teacher Survey Question Number 2

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.648(a)	3	.084
Likelihood Ratio	4.184	3	.242
N of Valid Cases	45		

4 cells (50.0%) have expected count less than 5. The minimum expected count is 16.

The results from Table 13 clearly demonstrate that the majority of the teachers at the four schools can hear noises outside of their classes during class hours. The significance reading of .084 on Table 14 claims that when comparing the aggregate responses of teachers among schools, the differences are not statistically significantly different. However, since there are four cells with less than five responses, the Chi-Square test does not prove that the data is not significantly insignificant.

Using a non statistical comparison method, one can clearly see that the results are similar and that a trend exists in the data. The majority of the teachers in all four schools can hear noises from outside of the classroom. One hundred percent of the teachers at Dr. Cesáreo Rosa Nieves, Rafael Martínez Nadal, and República Del Perú claimed to hear noises outside of their classrooms. Even 83.3 percent of the teacher at the last school, Sabana Llana, claimed that they could hear noises outside of their classroom during class hours. The fact that the majority teachers agreed on this question is important to our results because we can be confident that many schools in urban environments in Puerto Rico will answer the questions in a similar manner.

Question Number 3

The next question of the teacher survey asked the teachers what causes the majority of the external noise sources that they hear. Table 15 shows how the teachers responded to the question "What external noises to you hear the most?"

Table 15. Teacher Survey Question Number 3

		What makes the majority of these noises?							Total
		bus	car	Constru -ction	music	n/a	people	train	
CRN	Count	1	1	5	1	0	10	1	19
	% within School	5.3%	5.3%	26.3%	5.3%	.0%	52.6%	5.3%	100.0 %
RDP	Count	1	4	0	1	4	3	0	13
	% within School	7.7%	30.8%	.0%	7.7%	30.8 %	23.1%	.0%	100.0 %
RMN	Count	1	1	0	2	0	3	0	7
	% within School	14.3%	14.3%	.0%	28.6%	.0%	42.9%	.0%	100.0 %
SL	Count	0	0	0	0	3	3	0	6
	% within School	.0%	.0%	.0%	.0%	50.0 %	50.0%	.0%	100.0 %
Total	Count	3	6	5	4	7	19	1	45
	% within School	6.7%	13.3%	11.1%	8.9%	15.6 %	42.2%	2.2%	100.0 %

The results from the bottom row of Table 15 clearly show that teachers claim that people make the majority of the noises that they hear outside of their classrooms. These results are very consistent with what our group experienced during our time at each school. Short interruptions from voices affected 60 percent of our readings and caused increases in sound levels.

Although the majority of the teachers claimed that people caused the most noise, there was a significant amount of variation between the second and third most common responses for each school. The variation in the second and third most common responses is related to the type of environment that surrounds each school.

Teachers at the República Del Perú claimed that the majority of the exterior noises in their classrooms originated from cars followed by 23 percent of noise coming from people. The fact that teachers reported that cars produce more noise than people is related to the school's close proximity to the street. Surprisingly, our group observed that traffic caused 93 percent of the loudest noises during our sound level measurements. However, the teachers and our group both agreed that the majority of the noise originated from both traffic and people since people were the only other source of noise that we noted.

The teachers in Rafael Martínez Nadal, Cesáreo Rosa Nieves, and Sabana Llana all claimed that people produced the majority of the noises that they heard in their classrooms. Also, the response from each school was very similar with what our group observed in each school. The second most influential source that the teachers at Dr. Cesáreo Rosa Nieves described was the construction. These noises were responsible for 26.3 percent of the teacher's responses while our group observed that construction was the loudest source of noise 26 percent of the time as well.

Teachers from Rafael Martínez Nadal reported that the second and third sources of noise originated from music at 28 percent and cars at 14 percent. At Sabana Llana the teachers agreed that people made the majority of the noise that could be heard in classrooms. Teachers claimed that approximately 50 percent of the noise came from people.

With the exception of Sabana Llana, all of the schools responded very closely to Question Number 3 despite the fact that the order of the noise sources varied slightly between what the teachers observed and what we measured. Our group believes that the reason for the variation is because our sound level readings were only in two classrooms throughout the day. However, the teachers who responded were more likely to be located in different parts of the school since their classrooms are in different parts of the building. In schools such as the República Del Perú and Dr. Cesáreo Rosa Nieves, the classrooms in the center of the school are subjected to considerably less noise from the street or construction. Also, since our sound level readings were performed only in short intervals, the teachers' surveys might provide a more accurate reference for what percentages of the noises originate from different sources on a day-to-day basis. However, since our group and the teachers agreed on the top three sources of noise at each school, we believe that our results offer a very good indication as to what the major noise problems are at each school.

Question Number 4

The purpose of Question Number 4 was to determine if there were noises that teachers heard in class that we did not include in our survey. Table 16 showed what percent of the teachers in other schools could hear noises and Table 17 showed the results of the Chi-Square test that tests the differences between the schools.

Table 16. Teacher Survey Question Number 4

			Do you hear other noises outside of the classroom?			Total
			n/a	no	yes	
School Name	CRN	Count	1	2	16	19
		% within School Number	9.1%	.0%	90.9%	100.0%
	RDP	Count	0	1	12	13
		% within School Number	.0%	7.7%	92.3%	100.0%
	RMN	Count	0	1	6	7
		% within School Number	.0%	14.3%	85.7%	100.0%
	SL	Count	0	0	6	6
		% within School Number	.0%	.0%	100.0%	100.0%
Total		Count	1	4	40	45
		% within School Number	2.2%	8.9%	88.9%	100.0%

Table 17. Chi-Square Test for Teacher Survey Question Number 4

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.365(a)	6	.883
Likelihood Ratio	3.213	6	.782
N of Valid Cases	45		

8 cells (66.7%) have expected count less than 5. The minimum expected count is 16.

The results from Table 16 show that the majority of the teachers heard other noises on the survey, and Table 17 shows that the difference in responses among schools is not statistically different. However, since there are a large number of cells with an expected count less than five, the results of the Chi-Square test can not be used to definitively state that the results are not statistically significant. The information on Table 16 clearly shows that the more than 85 percent of the teachers at any school can hear other outdoor noises that our group did not include on the survey form.

Question Number 5

The response to Question Number 5 was the most important response because the responses to questions one through four were irrelevant if they were not louder than the teacher's voice. Table 18 below shows how teachers responded to the question "Do you feel that you are trying to talk over the outdoor noises?"

Table 18. Teacher Survey Question Number 5

			Do you feel that you have to speak over outdoor noises?		
			no	yes	Total
School Name	CRN	Count	2	17	19
		% within School Number	10.5%	89.5%	100.0%
	RDP	Count	0	13	13
		% within School Number	.0%	100.0%	100.0%
	RMN	Count	1	6	7
		% within School Number	14.3%	85.7%	100.0%
	SL	Count	2	4	6
		% within School Number	33.3%	66.7%	100.0%
Total		Count	5	40	45
		% within School Number	11.1%	88.9%	100.0%

The results from Table 18 show that the majority of the teachers felt that they must speak louder than noises that were infiltrating the classrooms from outside of the room. However, there was a difference between the percentage of teachers who could hear noise outside and those who claimed that they had to speak louder than the noises. For example, 100 percent of the teachers from Dr. Cesáreo Rosa Nieves, and Rafael Martínez

Nadal claimed that they could hear noise, but only 90.9 percent and 85.7 percent respectively claimed that they strained to speak over noise. On the other hand, 100 percent of the teachers at República Del Perú claimed that they had to speak louder than outdoor noises.

The most important point that the results of Table 18 demonstrate is that the majority of the teachers at all four schools claim that they have to speak louder than background noise. The fact that so many teachers responded affirmatively to Question Number 5 suggests that the teachers are aware of external noises and that they feel they must compensate for them by raising their voice.

Question Number 6

Question Number 6 is designed to determine whether or not teachers could hear noises coming from other classrooms inside of the building. Table 19 below shows how teachers responded to the question, "Do you hear noises coming from other classrooms?"

Table 19. Teacher Survey Question Number 6

			Do you hear noises coming from other classrooms?		Total
			no	yes	
School Name	CRN	Count	3	16	19
		% within School Number	15.8%	84.2%	100.0%
	RDP	Count	5	8	13
		% within School Number	38.5%	61.5%	100.0%
	RMN	Count	2	5	7
		% within School Number	28.6%	71.4%	100.0%
	SL	Count	1	5	6
		% within School Number	16.7%	83.3%	100.0%
Total		Count	11	34	45
		% within School Number	24.4%	75.6%	100.0%

The results of Table 19 show that 75.6 percent of teachers could hear noises that were coming from other classrooms in the building. However, the majority of the teachers who responded to this question indicated that the noises they heard were more often from students who were talking in the halls. Nonetheless, the results of Table 19 show that noises from other classes can be heard by teachers. These results are consistent with our sound level readings because we noticed an increase in the sound levels the majority of the time when adjacent classrooms were occupied.

Question Number 7

Question Number 7 asks teachers to identify the sources of noise from other classes, if they could hear noises in other classrooms. Since the results of Question Number 6 proves that teacher can hear other noises from classrooms, the results of

Question Number 7 are important since they will help to determine if these noises can be controlled or lowered. Table 20 shows the majority of the noises that teachers could hear in other classes.

Table 20. Teacher Survey Question Number 7

			If you answered yes to question 6, what makes the majority of the noise?		
			no	students	Total
School Name	CRN	Count	1	18	11
		% within School Number	9.1%	90.9%	100.0%
	RDP	Count	5	8	13
		% within School Number	38.5%	61.5%	100.0%
	RMN	Count	2	5	7
		% within School Number	28.6%	71.4%	100.0%
	SL	Count	1	5	6
		% within School Number	16.7%	83.3%	100.0%
Total		Count	9	36	45
		% within School Number	20.0%	80.0%	100.0%

The results from Table 20 show that almost 100 percent of the teachers who claimed to hear noises in other classes also claimed that those noises came from students. Only the two teachers from Dr. Cesáreo Rosa Nieves responded differently in Questions Number 6 and 7 because they claimed that the noises were not from other classrooms but rather from students in the hallways.

Question Number 8

Question Number 8 asks teachers if they felt like they had to speak over noises that originated from inside other classrooms. Table 21 shows how teachers responded to Question Number 8.

Table 21. Teacher Survey Question Number 8

			Do you feel that you have to speak over interior noises?			Total
			n/a	no	yes	
School Name	CRN	Count	0	3	16	19
		% within School Number	.0%	15.8%	84.2%	100.0%
	RDP	Count	1	4	8	13
		% within School Number	7.7%	30.8%	61.5%	100.0%
	RMN	Count	1	1	5	7
		% within School Number	14.3%	14.3%	71.4%	100.0%
	SL	Count	0	2	4	6
		% within School Number	.0%	33.3%	66.7%	100.0%
Total		Count	2	10	33	45
		% within School Number	4.4%	22.2%	73.3%	100.0%

The results from Table 21 show that the majority of teachers felt that they had to speak over interior noises that were in their classes. Fewer teachers at Dr. Cesáreo Rosa Nieves and Sabana Llana claimed that the noises they reported hearing in Question Number 6 were louder than their normal lecturing voice. However, the teachers at República Del Perú and Rafael Martínez claimed that they had to speak over all of the noises that they reported hearing in question six.

The results of Question Numbers 6 through 8 are important because they show that the majority of the teachers in all four schools could hear noises from students in other classrooms that were louder than their voices. These results indicate that there are times when the students' voices are excessively loud during class.

Question Numbers 9 Through 11

Question Numbers 9 through 11 are scale questions that are designed to determine how teachers would rate the level of noise and reverberation in their classroom. Since the responses to the question were answered on a discrete number scale, the result of the teacher surveys is most appropriately described using the median of the results and the median test to evaluate the variance. Question Number 9 asks teachers "In general, how loud would you rate the noise level in your classroom?" Question Number 10 asks teachers "How much does your voice echo when you are lecturing?" Question Number 11 asks teachers "How difficult do echoes make speaking in your class". The results of all three questions are summarized in Table 22 and the amount of variance between the schools was described in Table 23.

Table 22. Teacher Survey Question Numbers 9 Through 11

		School Name			
		RMN	CRN	SL	RDP
On a scale of 1 to 10, what is the noise level in your classroom?	Median	6	7	10	7
	%<= Median	67.0 %	72.7 %	40.0 %	53.8 %
On a scale of 1 to 10, how much does your voice echo in class?	Median	n/a	3	2.5	5
	%<= Median	n/a	54.5 %	67.0 %	38.4 %
On a scale of 1 to 10, how dificult do echoes make speaking in your class?	Median	n/a	4.5	4	6
	%<= Median	n/a	90.0%	50.0%	46.2 %

Table 23. Median Test for Teacher Survey Question Numbers 9 Through 11

	On a scale of 1 to 10, what is the noise level in your classroom?	**On a scale of 1 to 10, how much does your voice echo in class?**	**On a scale of 1 to 10, how difficult do echoes make speaking in your class?**
N	45	38	37
Median	7.00	4.00	5.00
Chi-Square	.791(a)	1.732(b)	2.394(c)
df	3	2	2
Asymp. Sig.	.852	.421	.302

a 4 cells (50.0%) have expected frequencies less than 5. The minimum expected cell frequency is 2.3.
b 2 cells (25.0%) have expected frequencies less than 5. The minimum expected cell frequency is 2.8.
c 2 cells (25.0%) have expected frequencies less than 5. The minimum expected cell frequency is 2.4.
d Grouping Variable: School Number

The results from Table 22 show that the differences in the responses among schools for questions nine through eleven are not statistically significant even though Rafael Martínez Nadal could not respond to questions ten and eleven. However, there are many cells that have a cell frequency that is less than the expected value. Unfortunately, the teachers at Rafael Martínez Nadal were unable to respond to questions ten and eleven since they were not included in the first copy of the survey. Since there were so many cells with low frequencies, the results of Table 22 do not accurately represent the significance of the material.

In Question Number 9, the median for all four schools is above six with a median as high as a ten in the case of Sabana Llana. The results of question nine clearly show that the majority of the teachers at all four schools agreed that the sound levels in their classrooms were on the higher side of a ten point scale. This result corresponds to our sound level measurements which are usually at least twenty decibels higher than the levels that ANSI recommends. Additionally, this question tells us that teachers perceive noise to be high in their classroom despite being surrounded by noise everyday.

In Question Number 10, teachers indicated that they did not notice much reverberation when they spoke during class since all of the medians are five or less. However, in Question Number 11, the median amount that the teachers chose rose approximately two points on the ten point scale. The results of questions ten and eleven indicate that teachers do not generally experience a problem with their voice echoing, but perhaps have to speak over echoes caused by other noises. This possibility is supported by our estimates of the reverberation time.

Our group estimates that the reverberation times in the room were slightly higher than the ANSI standards by approximately 33 to 148 percent. The fact that the reverberation times in some rooms were 33 percent higher than the ANSI recommendation explains why one person talking does not create as much reverberation. However, when there are more sources of noise that are not being absorbed, a student or teacher will likely be affected by a reverberation time that is 148 percent higher than recommended.

Question Number 12

The last question that we asked the teachers is "If more than one person is talking, do you have difficulty understanding the conversation?" Table 24 shows how teachers responded to this question.

Table 24. Teacher Survey Question Number 12

			If there is more than one person speaking, do you have problems understanding the conversation?			
			n/a	no	yes	Total
School Name	CRN	Count	0	3	16	19
		% within School Number	.0%	27.3%	72.7%	100.0%
	RDP	Count	0	3	10	13
		% within School Number	.0%	23.1%	76.9%	100.0%
	RMN	Count	7	0	0	7
		% within School Number	100.0%	.0%	.0%	100.0%
	SL	Count	0	0	6	6
		% within School Number	.0%	.0%	100.0%	100.0%
Total		Count	7	6	32	45
		% within School Number	15.6%	13.3%	71.1%	100.0%

The results from Table 24 show that the majority of the teachers who responded to Question Number 12 agreed that communication was difficult if more than one person was talking. While multiple voices can clearly make group communication difficult, incorrect reverberation time can also affect a person's ability to understand group conversations. The fact that 100 percent of the teachers from Sabana Llana replied affirmatively to question twelve and also claimed a higher median value for their amount of perceived echoes supported this claim. Also, Dr. Cesáreo Rosa Nieves and República Del Perú both claimed to perceive lower, comparable levels of reverberation in questions ten and eleven. Likewise, fewer teachers at Dr. Cesáreo Rosa Nieves and República Del Perú answered Question Number 12 affirmatively.

DRAWING CONCLUSIONS ABOUT CLASSROOM ACOUSTICS

So far our results and analysis have presented our data and described why each result was significant or not. But what was the point of gathering all of the data? What can we conclude about our results that will make a difference in Puerto Rico?

The main result of our noise study was the proof that none of the four schools that we studied were in compliance with ANSI standards. Our background research demonstrates that students across the world are all negatively affected when excess levels of noise are present in classrooms, when the reverberation is too high, and when students can not hear their teachers. Additionally, our research proved that the majority of people in Puerto Rico live in metropolitan areas and are more likely to be subjected to traffic noises.

We have shown that the noise levels are far in excess of thirty-five decibels using a widely accepted and proven standard. Moreover, we estimated that the reverberation times in all of the classrooms in our four schools exceeded the ANSI standard by at least 33 percent. In addition, the majority of the teachers that we surveyed claimed that the noises that they hear during class are louder than their voice. Based on prior research and our classroom noise measurements and teacher surveys, we reasonably can conclude that large percentages of students in Puerto Rico who attend schools in metropolitan locations are negatively affected by poor classroom acoustics. We did not attempt to demonstrate that the low aggregate standardized scores of children at the four schools were in some way a result of the excessive noise they experienced, but this possibility is an intriguing one.

Fortunately, our group also found results in our sound study that support the possibility that there are ways to reduce noise in schools without spending large amounts of money. First, we discovered that there were always areas in our schools that were at least five decibels quieter than the loudest sections of the school. Secondly, our group concluded that in the majority of the classrooms that we measured, the rooms were less noisy when students were not talking in adjacent rooms or hallways. Also, the majority of the teachers claimed that they often had to talk over students' voices that came from other classrooms. These results are inspiring since schools have the opportunity and power to reduce the noise in classrooms as a school community. For low-cost recommendations that we believe will improve acoustics in classrooms, we believe that every school on Puerto Rico will benefit from our study.

Lastly, our group has only begun to realize the wide-spread applications of reducing noise, not only in Puerto Rico, but also in the world. Our study was one of the first of many studies on the Island will find new ways to reduce the noise levels in classrooms and throughout Puerto Rico and the world. Fortunately for us, our project was able to give us the inspiration to research innovative ways to improve classroom acoustics. This inspiration and the search for ways to reduce solid waste on the Island led us to the discovery that solid waste materials can be used to improve acoustics in the majority of the buildings on the Island.

SOUND ABSORBING MATERIALS

As a result of our recognizing the existence of a low cost environmentally sound solution to the problem of excess noise, we decided to research new methods that would help to improve the acoustical environment in classrooms and in all types of buildings on the Island. We decided to concentrate our efforts on finding an innovative way to reduce the reverberation times in buildings in Puerto Rico. The results of our noise study show that reverberation times in classrooms ranged between 33 to 148 percent higher than the ANSI recommendation when the teachers left their windows open. However, if teachers shut their windows or if a school adds air conditioning to any classroom, the reverberation times in classrooms we measured, were almost 200 percent higher than what ANSI recommends.

The fact is that 69.5 percent of the materials that are used in commercial construction in Puerto Rico are either concrete or some type of masonry (Khandri & Morrow, 2003). These materials reflect more noise than almost any other material that one could place in a room (Bies & Hansen, 2003). The amount of sound energy that is reflected is taken into consideration by a number called the absorption coefficient. A 0.0 signifies complete sound reflection and a 1.0 represents total absorption. Concrete and masonry have sound absorption coefficients between .02 and .07 depending on the frequency of the sound wave that contacts the surfaces (Bies & Hansen, 2003). For all intensive purposes, concrete and masonry are completely reflective materials.

Our group interviewed two professionals in acoustical studies who work in Puerto Rico. Our first interview was with Professor Jorge Rocafort who is an acoustical engineer and a professor of Architecture at the University of Puerto Rico. He claimed that he experienced a lot of problems with reverberation in his work on the Island that was largely due to the building materials. He confirmed that many buildings on the Island had high reverberation. Secondly, we interviewed Dr. Sergio Caporali from the University of Puerto Rico Medical School. He is currently working on an occupational study of noise on the Island. He agreed that reverberation on the Island was problematic because of the large use of concrete.

Fortunately, there are many existing ways to reduce excessive reverberation in a room. The reverberation can be reduced by adding any material to a room that has sound absorbing properties (Bies & Hansen, 2003). It is common knowledge that many people solve reverberation problems by adding acoustical treatments such as acoustical ceiling tiles to the ceilings or by adding sound absorbing panels to walls. Theses materials are widely available and have been proven to be effective. However, in many cases their high costs make them an impractical solution. For example, the average cost of the acoustical ceiling tile in our cost analysis cost $4.90 per square foot of material. This means that someone would have to pay over $800 to add ceiling tiles to a thirteen foot by thirteen foot room!

Based on the high cost of existing acoustical treatments, our group decided that finding a lower cost product that was equally effective might enable not only the

Department of Education, but also a larger proportion of the general populace to use acoustical treatments. However, since the main focus of our project was to improve the acoustical environment in schools, we ultimately wanted to lower the price of acoustical treatments so some schools in Puerto Rico could afford them.

Our group determined that any idea that we would consider using would have to satisfy three criteria. First, the solution needed to be equally effective as a solution that was currently available on the market. Second, the solution would need to be less expensive than other currently available products. Third, the idea needed to be creative and innovative in the hopes that it could be further developed into a new product.

We decided to see what types of recyclable materials were available on Puerto Rico since they had the potential to be less expensive. Our group interviewed Antonio Rios, a director from the Authority of Solid Waste in Puerto Rico (Autoridad de Desperdicios Sólidos) and he told us that companies in Puerto Rico simply collected recyclable materials and shipped them to the mainland United States or to other countries. He said that he thought the Island could benefit if local industries could use the materials in manufacturing here. Data he provided indicated that Puerto Rican companies collected 139,776 tons of cardboard and paper, 43,569 tons of metal, and 22,775 tons of tires in the year 2005 (ADS, 2005). We decided that we would investigate the possibilities of using any of these materials for reducing sound.

Polyester Non-Woven Fibers

Through our research, we were able to find two studies that evaluated the feasibility of using polyester non-woven fibers as a sound reducing material. The study was initiated to find a use for textile waste fibers in Asia that were being deposited into landfills. These studies bonded the fibers together using heat in a process that is known a thermal bonding. Lin & Lou (2005) and Jou & Lee (2003) both concluded that thermally bonded polyester non-woven fibers could be used to manufacture sound absorbing materials. Appendix O shows the graphs of sound absorption coefficients for thermally bonded non-woven polyester fibers.

While the use of textile waste fibers for a sound absorption is impressive, it would not be feasible in Puerto Rico since there is very little textile manufacturing left on the island. However, our group realized that tires were made out of three major components: rubber, metal, and polyester and nylon fibers (Chicago Recycling Coalition, 2000). Upon further research regarding tire recycling, we discovered that during the tire recycling process, polyester and nylon fibers were separated from the rubber. Moreover, the only tire recycling company in Puerto Rico, REMA, currently discards all of their polyester waste in landfills (E. Velazquez, personal communication, April 24, 2007).

In addition, REMA currently is allowed to recycle only 60 percent of the tires on the Island because the Puerto Rican government allows other companies to grind tires for civil engineering uses. However, if REMA can demonstrate to the Puerto Rican government that they can recycle 100 percent of the materials in the tires, then they might be given permission to recycle the other 40 percent of tires. If there is a use for the steel and the polyester fibers, then simply grinding and burying the tires for fill would result in a waste of resources. Therefore, REMA would first remove the steel and the fiber and then the rubber could be used for other purposes.

Since REMA has the capacity to recycle 100 percent of the tires that are discarded each year in Puerto Rico, they are willing to give the polyester fibers away at no cost in the hopes that they can increase their crumb rubber sales by receiving permission to increase the amount of tires they recycle (E. Velazquez, personal communication, April 24, 2007). This means that any company that would use the materials would only have to pay freight charges that would be necessary to transport the materials back to their plant.

In light of this information, our group decided that the best way to make prospective manufacturers interested in making acoustical ceiling tiles would be to perform a cost analysis of the ceiling tiles. If the ceiling tiles were considerably cheaper than commercially available products, then we believe that any company who uses acoustical tiles would consider buying the cheaper alternatives instead. First, our group researched the cost of acoustical ceiling tiles that were currently on the market. Table 25 below shows the prices of seven different commercially available products.

Table 25. Price Comparison Chart for Acoustical Ceiling Tiles

Cost Comparison Table

Manufacturer	Model Name	NRC Rating	Price Per sq ft	Price per 2'x4' Tile	Material Cost for 576 sq ft Room	Material Cost for 20000 sq ft Building
NEW MANUFACTURER	NEW RECYCLED Minimum	0.8	$1.31	$10.50	$755	$26,200
NEW MANUFACTURER	NEW RECYCLED Maximum	0.8	$1.84	$14.73	$1,060	$36,800
Acoustical Solution Inc.	The Alpha-Enviro Ceiling Tiles	0.8	$2.63	$21.04	$1,515	$52,600
Sound Service (Oxford)	Echosorption	0.9	$3.40	$27.20	$1,958	$68,000
American Micro Industries	Symphony Acoustical Ceiling Tiles	1	$4.07	$32.52	$2,341	$81,300
Acoustical Solution Inc.	Signature Ceiling Tiles	0.8	$4.56	$36.48	$2,627	$91,200
American Micro Industries	Commercial Plus Ceiling Tiles	1	$6.22	$49.78	$3,584	$124,460
American Micro Industries	Softscape Acoustical Ceiling Tiles	1	$6.56	$52.50	$3,780	$131,260
SONEX Inc.	SONEX Acoustical Ceiling Tiles	0.7	$6.88	$55.04	$3,963	$137,600

The first two rows in Table 25 represent the minimum and maximum price that we, the new manufacturers, would want to charge for our recycled ceiling tiles. The price of the ceiling tile in the first row is 50 percent of the cost of the cheapest commercial product and is 20 percent of the most expensive product. The price in the second row is 75 percent of the cheapest commercially available product and 27 percent of the most expensive product. The two different prices demonstrate that even if hypothetical companies charged 75 percent of the next cheapest product, the total cost to acoustically treat a building would still be far less expensive than what currently exists. The four columns on the right offer an idea as to how much cheaper a project would be if our proposed recycled tiles were used rather than another commercially available product.

While a difference between $1.31 and $6.88 might not seem like an overwhelming difference in the price per square foot, the difference in the cost of adding two thousand square feet is drastic. For example, using our proposed recycled tiles would be $111,400 cheaper than the most expensive competitor.

The previous results does demonstrate that our material could be cheaper than commercially available products, but does it perform equally well in absorbing sound? The studies done by Lin & Lou (2005) and Jou & Lee (2003) claim that the NRC value for polyester is approximately .8 if the ceiling tiles are two inches thick. The NRC value is the number that is used in the consumer market to serve as a comparison factor between the sound absorbing capabilities of materials (STC Ratings, 2004). Thus, if two materials have the same NRC rating, then they have very similar sound absorbing capabilities. The third column of Table 25 shows that our proposed recycled tiles should perform as well as the cheapest commercially available product and actually perform better acoustically than the most expensive solution.

In order to demonstrate how much our proposed ceiling tiles would affect the reverberation time in a room, we used the measured results from one of our classrooms to make an estimation. Table 26 shows how much the reverberation could be lowered by covering the ceiling with our proposed acoustical ceiling tiles.

Table 26. Comparison of Reverberation Times With and Without Ceiling Tiles

Reverberation Time for República del Perú Room 2 (Open Windows)	
Reverberation Time (No Ceiling Tiles)	1.48 seconds
Reverberation Time (Our Ceiling Tiles)	0.40 seconds

Table 26 shows that by adding ceiling tiles, the reverberation in the classroom would be reduced below the suggested .6 second requirement that is suggested by ANSI. Table 26 assumes that the entire ceiling is covered in acoustical ceiling tiles. However, in some rooms with lower reverberation, the same result can be achieved by using less material. Table 27 shows the effect of covering 50 percent of the ceiling area with acoustical tiles in a room where reverberation is only 33 percent above the ANSI recommendation. Table 27 demonstrates that rooms with lower reverberation times require less material in order reduce the reverberation time below the ANSI recommendation.

Table 27. Comparison of Reverberation Times With and Without Ceiling Tiles

Reverberation Time for Sabana Llana Room 1 (Open Windows)	
Reverberation Time (No Ceiling Tiles)	0.80 seconds
Reverberation Time (50 % Ceiling Covered withTiles)	0.46 seconds

After we determined that ceiling tiles made from recyclable materials were effective and inexpensive, we had to determine if the idea of manufacturing the tiles would be appealing to local businesses. We contacted a company in the United States to determine the cost of the machinery that would be required for the thermal bonding process. The sales executive from the company informed us that there were machines made in Germany that could be easily modified to produce the end result that we desired. The German machinery would cost approximately $170,000 and could manufacture up to 13,046 pounds or 1,925 ceiling tiles per hour. There would also be additional $25,000 to $75,000 worth of machinery that would be required to clean, place, and cut the material.

The main factor that would limit production would be the amount of material that would be available on the Island. According to Eduardo Velazquez, the lead engineer at REMA, their company produces forty cubic yards of waste polyester per day (personal communication, April 24, 2007). We used a sample of the material and a scientific scale to estimate that REMA produced approximately 3,805 lbs to 5,708 lbs of polyester waste per day depending on the percent composition of our rubber and fiber mix. Also, we considered the case that REMA would be able to recycle 100 percent of the tires on the Island and estimated that the company would discard 9,514 lbs of fiber per day in this scenario.

In order to estimate how much profit a company could make in the first and second year, we took into account multiple expenses. Table 28 below shows an estimate of the amount of gross and net income that a company could make in their first year depending on the tile price and the amount of waste fibers produced by REMA per year. The table takes into account seven expenses and displays how much we estimate a company could make depending on the amount of waste fiber that is discarded on the Island per year. The two columns on the left reflect the minimum amount of polyester that is produced in Puerto Rico. The two columns on the right reflect the maximum amount of polyester waste that could be generated per year in Puerto Rico.

Table 28. Maximum and Minimum First Year Gross and Net Income

Expenses Vs Income

Minimum Production		Maximum Production	
Expense Description (2007)	**Expense amount**	**Expense Description (2007)**	**Expense amount**
Freight	$34,495	Freight	$34,495
Machine Operator Salary	$28,000	Machine Operator Salary	$28,000
Packaging Materials	$168,000	Packaging Materials	$252,000
Operating Utilities	$108,000	Operating Utilities	$120,000
Start Up Machinery and R&D	$600,000	Start Up Machinery and R&D	$600,000
Fire Proofing Chemicals	$500,000	Fire Proofing Chemicals	$750,000
Business Tax	$0	Business Tax	$0
Gross Income	$2,116,800	**Gross Income**	$3,175,200
Net Income	$678,305	**Net Income**	$1,390,705

For the first year, we estimated that a ceiling tile manufacturer would have to pay for freight, a machine operator, packaging materials, operating utilities of natural gas and electricity, and fire proofing chemicals. We assumed that any manufacturer would already have factory space and insurance and therefore would not have to pay for more rent or insurance. Also, in Puerto Rico there is 100 percent tax reimbursement for a company's first year in a new business and only a 7 percent maximum tax for the following years. Lastly, we estimated that the total start up cost would be approximately $600,000 for the start-up cost. This amount was based on $300,000 in machine costs and $300,000 in legal fees and engineering consultation.

Table 29 shows that in both the minimum and maximum cases, a manufacturer should be able to pay back his/her original investment and earn between $678,000 and $1,400,705 in the first year. Table 46 shows the amount that our group estimates a manufacturer could make in the second year of production. The increase in expenses and tile price reflect inflation over one year.

Table 29. Maximum and Minimum Second Year Gross and Net Income

Expenses Vs Income

Minimum Production		Maximum Production	
Expense Description (2008)	**Expense amount**	**Expense Description (2008)**	**Expense amount**
Freight	$35,678	Freight	$35,678
Machine Operator Salary	$28,960	Machine Operator Salary	$28,960
Packaging Materials	$173,762	Packaging Materials	$260,643
Operating Utilities	$111,704	Operating Utilities	$124,116
Fire Proofing Chemicals	$517,150	Fire Proofing Chemicals	$775,725
Maximum Business Tax	$153,258	Maximum Business Tax	$229,867
Gross Income	$2,189,194	**Gross Income**	$3,284,109
Net Income	$1,168,681	**Net Income**	$1,829,119

The main problem with our analysis is that we do not yet know exactly how high the demand for these acoustical ceiling tiles would be. We hypothesize that all of the tiles could be sold each year because three or four large contracts from construction firms in Puerto Rico or anywhere in the world would create enough demand for the supply. In the maximum production case, a manufacturer would produce 2,419,200 square feet of ceiling tiles per year. While that amount seems high, an office building that was four hundred feet long by four hundred feet wide would only have to be fifteen stories tall to use up all of the acoustical materials that could be produced on Puerto Rico annually. If these materials were made available world-wide, we believe a manufacturer would easily find customers to keep the ceiling tiles in demand. However, these ideas have not been proven and would require further investigation before they could be applied.

CHAPTER 5: CONCLUSIONS & RECOMMENDATIONS

One of the main objectives of this project was to provide recommendations for low-cost solutions for improving acoustical conditions in classrooms. The recommendations were designed for the schools involved in our study and for the Department of Education to apply to all schools throughout Puerto Rico. In order to complete this objective, we performed an evaluation of the current acoustical conditions in four local San Juan area schools. Our group completed extensive research on current acoustical treatments, the feasibility of using existing recycled materials on the Island, and an existing market for local companies to manufacture these treatments. This chapter lists and explains several recommendations we developed in order to improve acoustical conditions in classrooms on the Island.

RECOMMENDATIONS FOR THE DEPARTMENT OF EDUCATION

Our study revealed that the noise levels in Puerto Rican public schools were far in excessive of what research has shown to be ideal for learning. We believe that something needs to be done in order to provide the most suitable environment for learning as possible. The following describes the recommendations that our group is making to the Department of Education in Puerto Rico regarding noise in schools. These recommendations are a result of our investigation of noise in San Juan metropolitan public schools and are intended to improve the acoustical conditions in classrooms across the island. The recommendations are given as part of a three step phase.

Phase Number 1: Understanding Noise

First, ***our group recommends that the Department of Education encourage more sound studies in all of the public schools across the Island. We recommend that the Department of Education purchase low-cost sound meters that can be circulated through schools in order to perform the study. We recommend that these studies be done by the teachers and students as part of an interactive project to teach both students and teachers about noise. Our group recommends that the Department of Education develop a standard system in which to document the results of the noise study so the results can be used for later studies and efforts to reduce noise in classrooms***.

After all of the results from an island-wide study have been collected, ***we recommend that the Department of Education identify which schools on the Island are subjected to the most noise and which are subjected to the least***. From this data, the Department of Education should be able to see which schools need the most resources for reducing noise.

Phase Number 2: Developing Standards

Once the Department of Education has collected data from all of the public schools on Puerto Rico, ***we recommend that the Department consult an Acoustical Engineer in order to develop a set of acoustical classroom standards for the Island.*** Those standards should indicate what types of noise levels and reverberation times are acceptable for public schools**.** ***Our group recommends that the Department of Education uses the ANSI S12.60-2002 standards for guidance***. However, the ANSI codes are very strict and may be too stringent for the type of environment that exists on a highly-urbanized island using cement, masonry, and natural ventilation in most construction. ***Therefore, we recommend that the Department of Education outline what they believe, after consulting an acoustics professional, to be an acceptable set of acoustical standards for Puerto Rico, but taking into account the literature that addresses health and learning in relation to noise levels and ANSI standards***.

Phase Number 3: Beginning the Process of Change

Our group believes that schools can start making improvements to their acoustical environment as soon as this report is released***.*** ***We recommend that all public schools be retrofitted with or designed with noise and reverberation dampening materials.*** Potentially important materials are described in the next section. The Department of Education should urge schools to seriously consider making changes that will improve acoustics in classrooms. We recommend that noise is treated as a serious threat to learning.

After schools have started to make simple changes to reduce the noise in classrooms, ***our group recommends that the Department of Education consider allocating some funds for the schools that are faced with the highest levels of noise or reverberation***. We encourage the Department of Education to consider applying the commercially available acoustical solutions, possibly those listed under the school recommendation section below, to the noisiest schools on the Island (See Step Number 4). ***We also recommend that the Department evaluate specific ways to reduce noise in different schools***. For example, the República Del Perú might be able to benefit from the construction of a sound barrier since the majority of the school is one story tall and is located next to a major road. In contrast, the Sabana Llana would benefit more from increased efforts to reduce noise in the surrounding neighborhood since the school is two stories tall and not a good candidate for a sound barrier.

Additionally, we encourage the Department of Education to find alternate ways to find money for reducing noise in schools. For example, if the Department of Education considers using a new recycled product such as the sound absorbing tiles that we proposed, then perhaps the Department will be awarded grant money to install acoustical tile in some of the schools.

RECOMMENDATIONS FOR ALL PUERTO RICAN PUBLIC SCHOOLS

The following section is a description of the four steps, K.I.D.S., that we urge schools to take to improve the acoustic environment for the benefit of all students and teachers.

Step Number 1: Know Your Noise

The first thing that ***our group recommends is that schools take brief sound measurements throughout the entire school during a time when no students are in classes or on the school's property***. ***We recommend that schools identify the sections of the building that have the least amount of noise and which areas have the most amount of nois***e.

Once schools have selected which areas are the quietest, then each school should decide which classes would benefit the most from a quieter environment. For example, schools may choose to relocate any special education classrooms to the quieter area of the building since the students may already have difficulties learning. Classes that are already noisy by nature such as music or vocational classes should be moved to the louder sections of the building whenever possible. However, if schools have any empty classrooms, those rooms should all be located in the loudest section of the school if possible.

In addition, schools should identify what produces the majority of the background noise in their classrooms. Once again, each school should determine where excess noises originate from while there are no students in the school or on the school's property. Schools in Puerto Rico are located in areas called zone four quiet zones and sound levels must be below fifty decibels (Backiel; Day; Grouf; Stancioff, 2004). If the noise outside exceeds fifty decibels because of noise from local residents, ***we recommend that schools work with the residents to reduce sound.*** If residents continue to make noises that exceed fifty decibels, then ***we recommend that schools file a complaint with the Environmental Quality Board and request an investigation***.

In any case, ***we recommend that schools report the major sources of noise to the Department of Education so that the Department of Education can understand what sources disrupt schools the most***. All of the information that schools gather should be documented in a standardized way so that it could be used to make cases for quieter schools in the future.

Step Number 2: Involving Students

The second step to quieter schools is to educate the students themselves about the detrimental effects of noise.

Our group recommends that schools teach their students about how noise can affect their ability to concentrate and how noise has been shown to have negative physiological side-effects. Schools should use a sound meter or some other interactive display that shows students how loud different sounds can be and how much noise can disrupt concentration. Our group believes that learning about sound can be incorporated into an educational activity were the students themselves can help perform the sound level measurements. Lastly, ***our group recommends that teachers make students aware of how loud they can be during class time***. If there are excessive noise levels, we ***recommend that teachers urge students to lower their voices both in classrooms and in the courtyard***.

Step Number 3: Designated Quiet Zones

Our group's third step to reducing noise in classrooms involves the designation of a quiet zone. What exactly is a quiet zone? We define a quiet zone as a location in each school where students are required to keep their voices to a minimum. For example, a school could define the hallways, the classroom, the courtyard, and the library as quiet zones. While classes are in session, students should not talk in these areas since the noise from their voices was proven in our study to be disruptive to students and teachers alike. ***We recommend that schools post signs in quiet zones that help to remind students to be quiet and respectful while they are in these areas***.

If a school designates the halls and courtyards as quiet zones, then where are the students going to go during their free period? We do not expect nor recommend that students cease talking altogether, rather ***our group recommends that schools reserve one or two classrooms in the noisiest section of the building that can be uses as "break rooms"***. These rooms should be as far away as possible from other classrooms that are in session. Schools should encourage students to spend time in these rooms where their conversation will not be disruptive to students and teachers who are in class.

Our group understands that many students will not want to spend their free period sitting indoors when the weather outside is beautiful. Therefore, in addition to establishing "break rooms", ***our group recommends that schools should designate an outdoor area that student can gather during their free period***. This area, like the "break room", should be located in the loudest section of the school and as physically far away from other classrooms as possible. ***Our group strongly recommends that this area is not in the courtyard where the noise from their voices can penetrate the doors of most classrooms.***

In the cases of the "break room" and the designated outdoor area, we are only recommending that these areas are used during class hours. If all of the students in a school go to lunch at the same time, then noises will not interfere with classroom concentration and the issue is irrelevant. Likewise, once school is adjourned for the day, a quiet environment for studying may no longer be necessary. The recommendations in this section were written solely as a low-cost solution to reduce the amount of student-generated noise while classes are in session.

Step Number 4: Sound Solutions

The previous sections have discussed solutions that target the source of the noise. Many solutions that are applied outside of the building will still not sufficiently improve the acoustic conditions inside classrooms. For this reason, Step Number 4 of our recommendations discusses different ways that schools can reduce noise through the use of acoustical classroom treatments. The first set of recommendations that our group is going to make is changes the schools can make at no cost to them. The second set of recommendations involves solutions that show drastic improvements in acoustics but can only be installed at a cost to the school (See Appendix P).

Low-cost acoustical solutions

The first major problem that our group discovered in classrooms was how high the reverberation time could be when the classroom windows were shut. Therefore, ***our group recommends that all teachers open up their windows and doors if the windows and doors do not face a major source of noise***. If the courtyards of the school are free of noise, then teachers will not have to worry about closing their doors to block noise (See Step Number 3). Secondly, ***we recommend that teachers close any windows or doors if they do face sources of loud noise***.

Next, if students in a classroom have difficulty understanding their teacher, ***we recommend that the classroom be arranged in a closed format.*** This means that there would be one designated area where the teacher talks and all of the students are facing the teacher while he/she is talking. For example, if a teacher addresses his/her class from the front of the room, then all of the student desks should be facing the front of the room.

Lastly, ***our group recommends that schools measure the sound levels in every classroom that has fans or air conditioning units***. ***We recommend that the empty classrooms be first measured with the mechanical devices on and then with the mechanical devices turned off***. If there is a difference of more than three decibels between the two measurements, then ***we recommend that teachers try to avoid using the devices whenever possible***.

RECOMMENDATIONS TO SPECIFIC SCHOOLS

Since four specific schools' noise pollution levels and acoustical conditions were evaluated in this project, our group made some additional specific recommendations to each school based on our observations and findings.

Dr. Cesáreo Rosa Nieves

During our visitation to this school, we found high noise levels due to nearby construction. It was explained to us by a faculty member of the school that the construction started in 2006 and would continue until 2010. We discovered that the school population had recently been reduced by half due to student relocation to other local schools. Due to this decrease, our group observed that empty classrooms were scattered throughout the school. Since our sound level measurements for this school showed a significant difference between the loudest and quietest section of the school, we ***recommend that all classes should be conducted in the quieter section of the school***. If possible, ***we recommend that all of the students should be relocated to the sections of the school that do not directly face the construction***.

Rafael Martínez Nadal

Our group made two important observations that could be used to make recommendations for this school. First, we observed that the loudest section of the school was the section of the school that faced the street. In this area, classrooms were subjected to noises from passing traffic. We recommend that classrooms keep any windows facing the street closed and the windows and doors facing the courtyard open. Also, ***our group recommends that the school carefully decide which classes to locate in the loud section of the building.*** Secondly, our group observed that there was a large amount of land in the rear of the school. Additionally, there was a basketball court that was located on the far end of the school's property. ***Our group recommends that teachers at Rafael Martínez Nadal use this area by the basketball court as the designated outside area to be used during free-periods. We recommend that students are urged to be quiet when they traverse to and from this area***.

República Del Perú

During our visit at this school, we immediately noticed how close the school was to the main street. One of the rooms that we investigated had an air conditioning unit.

Since we found that classrooms with windows shut on the traffic side reached levels as low as those located away from the road, ***we recommend windows facing traffic should remain closed***.

Sabana Llana

During our visit to Sabana Llana, we observed that the main sources of noise in classrooms that faced the street were traffic and music. Most of the music that interrupted our noise readings originated from cars that passed by the school with their windows open. However, we spoke with teachers that told us that, in many cases, people in the adjacent public housing complex would play loud music during the school day. They claimed that these noises could be very distracting throughout the school day.

We recommend that the school files a complaint with the Environmental Quality Board and requests an investigation of the noise in the public housing project during the day. In addition, ***we recommend that classrooms facing the street and the housing complex keep their doors closed completely while class is in session***.

Our group also observed that there was a basketball court in the courtyard of the school where many students gathered throughout the day. Noises from their voices were present in all of our sound level measurements except for when the students were at lunch. We recommend that the students use this area only during times when other classes are not in session. The noises from students in the courtyard can reach every classroom from this location. ***Our group recommends that the school consider designating another area outdoors where students could gather during their free period.*** We believe that if there is less noise in the courtyards, then all of the classrooms in the building will be able to open up their window without a significant increase in sound levels.

RECOMMENDATIONS FOR PROSPECTIVE MANUFACTURERS OF ACOUSTICAL CEILING TILES

The recommendations in this section are based on our group's cost analysis and research involving the manufacture of acoustical ceiling tiles made from polyester waste fibers. Based on the analysis, we believe that any manufacturer on the Island could pay back their original investment within one year assuming that they already own a manufacturing facility. In addition, we believe that the local construction industry will provide sufficient demand to allow an acoustical tile manufacturer to sell all of the tiles that they produce annually. However, since we could only dedicate three weeks to the research of these acoustical tiles, there are a lot of areas of our idea that still need to be investigated. Our group has recommendations that we believe will help a local manufacturer transform our ideas into profit. (See Appendix P)

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APPENDIX A

SPONSOR DESCRIPTION

University of Puerto Rico at Rio Piedras

The University of Puerto Rico is the oldest and largest university system in Puerto Rico. It is made up of eleven campuses and has a total student population of nearly seventy thousand. These campuses are located in: Aquadilla, Arecibo, Bayamón, Carolina, Cayey, Humacao, Mayagüez, Ponce, Rio Piedras, and Utuado. Additionally, there is a Medical Sciences Campus located in San Juan. Although all of these campuses have different focuses on academics, they are all looked over by the president of the entire university system. The current president of the University of Puerto Rico is Antonio García Padilla. Mr. Padilla was himself educated at the University of Puerto Rico and received his undergraduate degree in 1974 and his law degree in 1978. He continued to attend school and received an LL.M. from Yale Law School in 1981.

In addition to the president of the entire university system, each individual campus is represented by a chancellor who is nominated by the president. This chancellor is in charge of administration at his or her respective campus. The chancellors are also responsible for appointing deans of the university to help with administration (Puerto Rico Code, 2002). The current chancellor of the Rio Piedras campus is Gladys Escalona de Motta (University of Puerto Rico at Rio Piedras, 2006).

The campus at Rio Piedras is located in San Juan and is responsible to teach the students of Puerto Rico science and the arts as well as educating them of the importance of the culture of Puerto Rico. The University aspires to educate the students at the university along with providing services to the community and to “collaborate with other organizations, within its appropriate sphere, in the study of the problems of Puerto Rico" (Puerto Rico Code, 2002).

The University of Puerto Rico at Rio Piedras was the first public university in Puerto Rico and was established in March of 1903. The University is the largest of the University of Puerto Rico system and has a student population of approximately fifteen thousand undergraduate students and another four thousand graduate students (University of Puerto Rico at Rio Piedras, 2006). The campus covers about 275 acres and employs over 1,000 faculty members.

At the Rio Piedras campus, there is an Academic Senate that is the official medium of the academic community. The Senate deals with issues such as establishing academic rules, work together with other campuses in the university system, and completing any other tasks outlined by the General Rules of the University of Puerto Rico.

The Rio Piedras campus offers many sports to attending students. These sports include, but are not limited to, swimming, baseball, soccer, football, tennis, volleyball, basketball, water polo and softball. The athletic department has a philosophy that provides "the student-athletes, through the sport, an education of first quality, offering experiences of discipline, responsibility, leadership and comradeship" (University of Puerto Rico at Rio Piedras, 2006).

The Social Sciences department of the University of Puerto Rico at Rio Piedras has the mind set that follows the mission statement of the University and the objectives of the Faculty of General Studies (University of Puerto Rico at Rio Piedras, 2006). The department has many goals for its students. One of the main goals of this department is to help the students develop skills to integrate their knowledge of the world and culture. Another goal is to familiarize the students with the disciplines of Social Sciences and their relations with other humanistic and scientific disciplines (University of Puerto Rico at Rio Piedras, 2006). Thirdly, the department tries to develop an understanding of the basic elements of methodology used by social scientists (University of Puerto Rico at Rio Piedras, 2006). This is so the students can identify and use some of the techniques and procedures of Social Sciences. The Social Sciences department helps teach students valuable lessons regarding research and culture.

APPENDIX B

MECHANICS OF SOUND AND NOISE

Summary of (Bies & Hansen, 2003)

Introduction to Sound and Noise

The study of sound is a very complicated subject that requires an extensive background in science, math, and engineering. However, there are some basic fundamentals to understanding noise that will be useful for this project. This chapter of the appendix will serve as a guide to better understand the subjects that our group is going to encounter in our project.

What exactly is sound? Sound is an interpretation made by the human ear when the ear senses a change in pressure. This change of pressure is generated when something called a sound wave passes by our ear. Sound waves usually occur when there is a compression in a fluid that causes a change in pressure. For a certain pressure change, or acoustic pressure, the ear interprets a certain sound. A healthy human ear can hear a minimal acoustic pressure of 20×10^{-6} Pascals which corresponds to four thousand Hertz. On the other hand, pain is experienced when the acoustic pressure levels reach sixty Pascals.

Sound travels to the human ear at a speed denoted as the speed of sound or c. The speed of sound, c, is defined as $c = \text{sqrt}(D/\rho)$. Where D is the stiffness and ρ is the density. For most cases, sound that humans hear travels in air. The speed of sound for air at twenty degrees Celsius and one atmosphere of pressure is approximately 343 meters/second.

As previously mentioned, sound travels in the form of a sound wave. In reality, the study of every single sound wave that propagates from a source is extremely complicated. To make an analytical analysis of sound waves possible, sound waves can be described as being either planar or spherical waves. A planar wave is one dimensional and a spherical wave is described in terms of spherical coordinates.

Two things occur when these sound waves propagate through a fluid. The waves pass energy to the fluid, or transmit energy to the fluid, and the waves transmit acoustical power. The amount of energy that is transmitted to a fluid is referred to as sound intensity, while the amount of power transmitted to the fluid is know as sound power.

One important thing to understand about a sound wave is how and where it can propagate or travel from. Noise can propagate through a fluid, such as air or water, or noise can propagate through a solid structure. The source of the noise is important to understand when a solution is going to be considered. For example, if a classroom is noisy because of outdoor traffic, noise is propagating through the air, and then increasing the sound transmission loss of an outdoor wall could reduce the background noise levels of the classroom. However, if there is a noisy ventilation unit that is causing one of the classroom's walls to vibrate, then efforts need to be taken to control those vibrations from within the utility room.

Where Does the Decibel Come From?

As previously discussed, sound is an interpretation of a pressure change caused by a sound wave. The pressure is measured in units of force /unit area. While the sound power and sound intensity can be changed linearly, the human ear is not capable of responding to a linear change in energy. For example, a sound that is twice as loud does not transmit twice the amount of energy. The ear responds logarithmically to a change in sound energy. For this reason, a logarithmic sound scale is useful in determining the difference between sounds as a human would hear them. The sound pressure level, L_p, is a comparison of a sound pressure that is exerted and the lowest sound pressure a human ear can hear. The units of L_p are in decibels and are the quantity that is measured by a sound level meter.

Because sound levels are measured in decibels, any mathematical operations that must be performed on a sound level measurement must be done with special consideration. For example, a classroom is being measured for noise with an air conditioning unit turned on, and the sound level is measured to be seventy-five decibels on average, and then the air conditioning is turned off and the sound level is measured to be seventy decibels on average. If the goal is to determine what the noise level of the air conditioner is by itself, then the following formula must be used:

$$L_{pm} = 10\log_{10}[10\text{^}(75/10) - 10\text{^}(70/10)] = 73.35 \text{ dB(A)}$$

This equation signifies that the air conditioner operates at 73.35 decibels on average. Even though this example is fairly straight forward, the goal of this example is to show the reader that any mathematical operations involving sound level measurements need to be verified by a sound engineering text.

For the application of noise reduction, an understanding of the decibel and how loudness is perceived is an essential skill. Studies by (Stevens, 1957; Zwicker, 1958; Zwicker & Scharf, 1965) show that by decreasing the sound energy by a factor of ten, or decreasing the sound level by ten decibels, that a human ear will perceive the change as being half as loud. A decrease of three decibels is classified as “just perceptible”. These studies show how much sound pressure needs to be reduced in order to change a human’s perception of loudness.

In addition to the sound pressure affecting a person’s perception to loudness, the frequency of the sound wave is also important. For example, a sixty-three Hertz tonal noise wave with a sound level of sixty decibels sounds as loud as a one thousand Hertz tonal wave at forty decibels. This simple example shows the importance of considering both the sound pressure and the frequency when determining how “loud” a room is.

What is an A-Weighted filter? Why Use a Filter?

In the previous section, it was shown that the loudness of a sound depends on the sound pressure level, but also on the frequency of the sound wave. Just like other aspects of sound, accounting for each frequency and how its loudness is perceived is very complicated. The way that different frequencies are accounted for in sound level meters is through the use of a weighting system. There are three standard weighting filters that are commonly used; A, B, and C weighted filters. These filters, when applied to a sound meter, record a decibel level as the human ear would perceive it. An A filter accounts for sound pressures below about fifty to fifty-five decibels. The other filters account for higher sound pressure levels. These weighting systems are very important to understand when measuring sound levels because different filters will give you a different response. In the case for measuring classrooms, the A-weighted filter is of most concern (ANSI, 2002). When any standard is written in decibels on average for example, the letter in the parenthesis indicates the type of filter that was used or is required for that reading.

What types of Sound Level Meters Exist?

There are two main types of sound level meters. One type is a traditional sound level meter that displays the measured values on a screen that the user can read. Some of these meters are capable of a SLOW averaging display that will take a reading and display the average sound level for that interval on a screen so the user can record the data manually.

The second main type of sound meter is statistical analysis sound level meter. These meters take sound level readings in real time and input the values into a computer. From there, the measurements are plotted on a time series plot. These types of meters have different analysis numbers that can be calculated for a set of recorded data. These readings are L_{10}, L_{90}, and L_{eq}. L_{10} is the sound level that was exceeded for 10 percent of the measurement time. L_{90} is the sound level that was exceeded for 90 percent of the measurement interval. L_{eq} is the average sound level of the entire measurement interval and L_{Aeq} is the average sound level when an A-weighted filter is used.

What Is Reverberation Time and How Do I Calculate It?

When a sound is generated by a source within a room (i.e. a teacher's voice), that sound wave will propagate until it comes into contact with a surface. If the surface is reflective, the wave will reflect off the surface and a reverberant field is formed. The shape of the room and its materials strongly affect how the reverberant field forms. In reality, the total amount of sound energy in a room is the amount that is directly coming from a source and the amount in the reverberant field.

The reverberation time is the time it takes for the sound level in a room to decay sixty decibels. One important aspect about the reverberation time is that different frequencies of sound will reverberate differently within a room. Many reverberation testing methods, such as the one described by ANSI, measure the reverberation time in a room for multiple frequencies.

There are two ways to measure the reverberation time. The first method involves a sound emitting source such as a speaker that emits different frequencies. The source emits sound, the source is shut off, and then a sound level meter is used to measure the time required for the sound level to decay sixty decibels. Most methods use five hundred Hertz, one thousand Hertz, and two thousand Hertz for the different frequencies.

The second method for calculating the reverberation time is an estimation process that uses Sabine absorption coefficients and geometric measurements. There are many recommendations for the reverberation time depending on each room's function. Also, there are different equations that can be used to measure the reverberation time. For the purposes of this project, our group will use the Sabine formula T_{60}=kV/A. T_{60} is the reverberation time. K is a constant = .161 s/m or .049 s/ft. V is the room volume. A is the sum of all the surface areas multiplied by their respective Sabine absorption coefficient (ANSI, 2002).

APPENDIX C

POSSIBLE ACOUSTIC AND NOISE CONTROL SOLUTIONS

Introduction to Acoustical Solutions

The ultimate goal of this project is to reduce the occurrence of troublesome background noise in schools, if in fact excessive noise is a problem that exists. Although the main focus of the project is to deeply understand the noise levels in public schools, it is also important to have a basic knowledge of the types of noise remedies that exist. As previously stated in the report, the origins of noise in a classroom cannot be predicted with certainty until someone has physically measured and observed the sound in a classroom. Additionally, the report has shown that not all acoustical problems in classrooms are associated with a high background noise level but also with factors such as reverberation time. The type of solution that will be viable for a classroom or school strongly depends on the acoustical findings that researchers will measure. This appendix will introduce the reader to possible solutions for excessive external noise levels, excessive internal noise levels, and incorrect reverberation time in a classroom setting.

Noise Barriers

Summary of (Kotzen, 1999)

If the major source of noise in a classroom or building is outdoor noise pollution, then noise barriers can be an effective way to lower sound levels inside classrooms. For example, if a school is in close proximity to a major highway, then a proper noise barrier could decrease the noise levels adjacent to the school walls. However, the selection and design of the noise barrier are critical to the overall effectiveness of the partition. STC ratings (2004) describe that a flanking path, or possible gap or weakness where noise penetrates a barrier, can negate the overall effects of the partition.

There are also many environmental concerns with the construction of a noise barrier. The barrier has to comply with local building codes and should be designed to compliment the appearance of the surrounding area instead of degrading it. When a noise barrier is built in a pedestrian area, special concerns need to be taken to keep the wall in proportion with humans. The wall's designer would not want people to feel intimidated or uncomfortable being next to the wall. In fact, Kotzen claims that in urban areas, people can feel uncomfortable if they can not see what is on the other side of a wall. Fortunately, there are many different barrier designs that are appealing to a wide range of locations and price ranges.

Earth mounds are a type of noise barrier that are commonly used alongside major highways. The benefit of an earth mound is that extra earth removed during construction can often be used to build these mounds. In addition, these mounds have a natural appearance and can be easy to maintain. These mounds are very effective in reducing noise, but have to be built higher and much wider than other types of barriers. For example, a 7 meter tall vertical concrete wall is equally effective as a 9.5 meter tall earth mound. In designing earth mounds, the designer must consider the issues of drainage, mound slope, and the possible need for planting foliage before they make a decision to build the barrier.

Timber barriers are a vertical type of barrier that is constructed with treated timber boards and usually supported by steel beams anchored in concrete. These barriers blend into rural areas well, but are also fitting in urban and suburban locations. In some cases, timber barriers are built inside a planter so that plants can be planted around the walls to improve its overall appearance. In the designing of the walls, the designer should be conscious of making materials compatible. For example, Kotzen argues that an earth colored timber structure appears displeasing to the eye when contrasted against a gray concrete wall or bridge. Fortunately, timber barriers are very affordable compared to other types of barriers and their maintenance consists only of periodic treatments.

Sheet metal barriers are a type of noise barrier that is usually absorptive in nature. An absorptive wall absorbs a percentage of sound energy as it comes into contact with the partition rather than reflecting it. In general, sheet metal barriers use perforated metal fronts with solid rear sections. The type of metal that is most commonly used is aluminum because it does not rust like steel. A major benefit of sheet metal barriers is that they are simple and are compatible in many locations. The partition can be made with different designs, shapes, or painted in different colors to compliment the local landscape. These types of barriers have been used extensively in Europe. The cost to maintain these walls is very low and consists of periodic inspection, cleaning, painting, and tightening of bolts.

Concrete barriers can be designed in two ways. They can be either reflective or absorptive. Reflective concrete barriers use standard concrete mixes to reflect noise. These walls can be built in urban, suburban, and rural areas. In addition, the walls can be terraced and plants can be grown in the walls to make them more visually pleasing. Also, the texture or designs can be molded into the walls to produce different designs to create interest in the wall. These types of walls can also be built with concrete cinder blocks or bricks and be extremely effective as well. Absorptive concrete walls are built using wood-fiber or small granular concrete balls as aggregate. Both types of concrete and brick walls have a very low cost of maintenance associated with them.

Plastic, PVC, and fiberglass barriers are newer types of barriers that are becoming more economically feasible as plastic prices decrease. These types of barriers can be made from recyclable materials. One advantage of plastic is that it can be molded into a pattern to look like another material. For example, plastic panels can be molded to look like timber if the design calls for a "timber look" in the area. In addition, vines or other types of plants can be grown on these walls to make them appear biological. However, if plants are grown on these barriers, then the maintenance costs increase because the walls have to be cleaned and the plants have to be watered and trimmed.

Transparent barriers are advantages because they can be made of multiple materials and can be completely transparent or screened to be semi-transparent. These barriers can eliminate issues of shadowing and they make areas feel less confined than other types of barriers. Transparent barriers are made from laminated, reinforced glass or from acrylic or polycarbonate sheets. Acrylic sheets can be cut to shape on site, but do not remain transparent as long as glass barriers do. Unfortunately, glass barriers can be broken if hit hard enough, and acrylic barriers are easily scratched by vandals. The major disadvantage of transparent barriers is their high cost to maintain.

The last type of noise barrier is a biological barrier or "living wall". These barriers are called so since plant life makes the integral part of their sound reducing material. There are many things to consider when building a biological barrier. First, plants have to be compatible with the soil type used for planting. Secondly, plants can not be too densely planted otherwise they can kill each other. Thirdly, the plants must be able to survive any severe winds or storms that they will be exposed to. Since the plants make up an integral part of the wall noise reducing capabilities, if all the plants die out, then the wall's effectiveness can be greatly reduced and can be an eyesore. For this reason, the barrier needs to have a sufficient irrigation system and full maintenance plan. One advantage to this type of barrier is that it takes up sufficiently less space than an earth mound and it can be used as a substitute for earth mounds. However, the cost of irrigating and maintaining these walls can be high depending on the climate and the type of plants used in them.

Classroom Noise Solutions

Summary of (ASHA, 2005) and (ANSI, 2002)

As previously discussed in this report, not all background noises originate from outdoor sources. If sound level measurements of classrooms reveal that there is excessive internal noise or if incorrect reverberation times are present, then exterior noise barriers will be ineffective in reducing these sources of acoustic deficiency. Moreover, there are different solutions for solving internal noise problems depending upon the exact source. ANSI lists standards that are important when designing new school buildings. These standards include guidelines that recommend HVAC and plumbing setups along with wall design and materials; however, if a school has already been built, then major renovations may be too costly.

Fortunately, there are other options that can help improve acoustics in classroom. One such option is to rearrange classrooms. If one side of a school is louder than the other, then classes that require speech recognition like language and reading could be relocated to quieter parts of the building. Another option is to improve the STC ratings of partitions between classrooms. If a classroom is adjacent to a loud room or corridor, then the separating walls can be rebuilt to be more sound proof. Also, doors and other separating features can be replaced to reduce sound transmission. If there are machines in utility rooms that are transmitting vibrations through class walls, then the machines can be insulated with vibration reducing materials to lower the structure-born noise levels that enter a classroom. If there are pre-existing pipes or ventilation ducts in a classroom, then they can be insulated to help reduce the amount of noise that they contribute to the classrooms. Lastly, equipment in classrooms that generate noise can be moved around the classroom to find a position that is the least disruptive to the teacher's voice.

Correcting Reverberation Time

Summary of (ANSI, 2002), (ASHA, 2005), and (Bies & Hansen, 2003)

As stated in this report, having the incorrect reverberation time for a room is detrimental for speech recognition. If sound remains in a room for too long, then the teacher will be competing against her own voice when she is talking to the students. If sound does not remain in a room long enough, then some student will be straining to hear every word that is coming out of a teacher's mouth. The amount of sound absorbing material in a room can increase or decrease the reverberation time. Too much reverberation requires more sound absorbing material and too little reverberation requires less sound absorbing material. Sound absorbing material can be material like carpets, sound panels, acoustical ceiling tiles, and even students. Unfortunately, some of these materials can be expensive; however, actions like putting tennis balls or plastic tips on students' chairs can be an inexpensive way to eliminate extra noise sources from reverberating.

APPENDIX D

OUTDOOR OBSERVATION FOR SCHOOLS

Object	Observation
Building Appearance	
Existing Fencing (y/n) Describe	
Proximity to Street (Wall 1)	
Proximity to Street (Wall 2)	
Proximity to Street (Wall 3)	
Proximity to Street (Wall 4)	
Proximity to Street (Wall 5)	
Proximity to Street (Wall 6)	
Proximity to Street (Wall 7)	
Proximity to Street (Wall 8)	
Building Wall Material	
Possible Noise Sources	
Existing Foliage (y/n) Describe	
Roof Material	
Number of Stories	
Windows (y/n) Describe	
Overall Neighborhood Appearance	

Exterior Building Diagram

(place sketch here)

Definitions

1) The building appearance is a description of the quality of the building. Is the building in good repair or does it need work? Are there any visible hazards or possible noise leaks that are obvious?

2) Existing fencing can be any material that is used as a barrier for sound or people. The observation should list the material and a physical description of the fence.

3) The proximity to street measurements are measurements in feet that must be taken from each street facing the wall of the school to the edge of the street. Each wall should be numbered on the exterior school diagram. These measurements will demonstrate how close the school is to potential traffic noise as well as offer insight to the feasibility of an outdoor sound barrier.

4) The building wall material should be the most accurate material description possible. If the walls are made of multiple materials then describe and list which wall numbers are made of which material.

5) The possible noise sources are any sources of sound that could be present or could be a problem at a later time. The observation should list all possibilities. A temporary source of noise, such as a construction site, should be noted as it might be a source for error in sound level measurements.

6) The existing foliage should be listed or described to the fullest extent possible. This measurement will offer insight to possible plant covering if an exterior wall is recommended for the site.

7) The roof should be observed for the type of material and for existing conditions. The roof material is an important factor if there is an airport nearby.

8) The number of stories should be described and any noticeable differences between stories should be listed. This data can be used to assess sound barrier feasibility.

9) The windows observation should describe which walls have windows if any. In addition, the type of windows should be listed i.e. double pane glass. This data is important because windows are often the weak point to a wall's sound reducing capabilities.

10) The neighborhood conditions should note how well the school fits into the surrounding neighborhood. Describe whether or not the school appears to be an eyesore or vice-versa.

APPENDIX E

INDOOR AND CLASSROOM OBSERVATIONS

Indoor Observations **Object**	**Observation**
Existing pipes	
Ventilation	
Mechanical devices	
Hall material	
Hall width	
Lockers	
Wall hangings	
Frequency of students	
Frequency of disturbance	
Other	

Hall Diagram

Include cafeterias, gymnasiums, music rooms, and other noise sources with class numbers

(place sketch here)

Classroom Observations

Object	Observation
Overall Classroom Appearance	
Wall 1 Area	
Wall 2 Area	
Wall 3 Area	
Wall 4 Area	
Additional Wall Area	
Floor Area	
Ceiling Area	
Classroom Volume	
Wall Material and Surface Coating	
Floor Material and Surface Coating	
Ceiling Material and Surface Coating	
Teachers Desk Material and Area	
Students Desks Material and Area	
Window Conditions	
Windows Facing Street	
Mechanical Noise Sources	
Other Possible Noise Sources	
Floor Number	
Adjacent Rooms	
Open or Closed Layout	
Sound Absorbing Material (type/area)	

Classroom Dimensions Diagram

(place sketch here)

Classroom Layout Diagram (with materials listed and numbered)

(place sketch here)

Definitions

1) The overall classroom appearance should give a general description of the classroom while sighting any areas that appear to need improvement.

2) The wall area measurements should be measured in square feet and should be performed for each wall.

3) The floor and ceiling area should also be measured in square feet.

4) The room volume should be measured in cubic feet. All of the above measurements are necessary for estimating the reverberation time in the case that access to measurement equipment is not possible. Tables usually contain Sabine absorption coefficient criteria for materials in metric units.

5) The wall, ceiling, and floor material observations must be as accurate as possible. Walls that are made up of different materials must be listed separately. The surface coating measurement should describe if an object is covered in a substance, such as paint or wallpaper. In addition, the texture should be described. These properties are used to estimate the reverberation time in a room.

6) The teacher and student desks should each be individually measured and listed in square feet. If the student desks are identical, then only one needs to be measured and the number of desks should be indicated. In addition, the desk material should be listed for each desk and chair if there are any inconsistencies.

7) The windows in the classroom should be listed and described if there are any present. Also, if the windows face the street or any other possible noise source, it should be noted. The analysis of the windows should be done carefully because they may be a large contributor to the noise level inside classrooms.

8) Mechanical noise sources, or any device that produces noise when in operation, should be observed and listed. If a classroom has a fan or air conditioning unit, or if a classroom is next to a utility room, then those sources should be described.

9) The floor number should indicate whether or not there are other classrooms above or below the testing classroom. For the second method of testing sound levels in classrooms, first story classrooms should be tested to see if they experience noise infiltration from the above classrooms.

10) The adjacent room observation must list all of the adjacent classrooms and indicate what possible sources of noise could originate from each one.

11) The classroom layout can be described as either open or closed. An open classroom consists of multiple rooms or divisions that might interfere with a

teacher's voice. A closed classroom is a single room with no intermediary divisions. All of the students are in a single room.

12) Lastly, all materials that could potentially absorb sound, according to the Sabine absorption coefficients, should be listed by their name, location, and respective area in square feet. This information is important in estimating the reverberation time.

APPENDIX F

OUTDOOR SOUND LEVEL MEASUREMENTS

Measurements According to ASTM Standards Vol .04.06-2006

Outdoor Sound Level Measurements with a Statistical Analysis System

For the purpose of this project, the type of outdoor sound level meter will be a statistical analysis type that corresponds to ANSI Type 1 Standards. The sound level meter should be capable of at least sixty decibels dynamic range. These outdoor measurements will be performed with both A-weighted and C-weighted filters. The sound meter should have an outdoor microphone system with a windscreen. Also, the sound level meter should have a preamplifier and should be mounted on a tripod for the duration of the measurements.

Before Taking the Measurements

Before the measurements are taken, the wind speed, relative humidity, and the temperature should be recorded for potential effects on the instrumentation. In addition, the barometric pressure should be measured and a picture of the equipment setup should be taken for documentation purposes. Lastly, the sound level meter must be calibrated before and after each continuous measurement period. The calibration should be performed in compliance with the manufacturer's guidelines.

Measurement Procedure

The first aspect to the measurement procedure is to select the measurement location. For the purpose of this project, all sound level measurements will be taken between the times of 11:00 a.m. and 2:00 p.m. The measurer should carry the sound meter around the school premises and identify the four to six places where the sound level readings are the highest. All locations must be at least five meters from each other. Any brief loud noises such as an airplane should be ignored when determining the loudest locations. Next, the physical description of the exterior should be observed as described in Appendix F.

The next step in the measuring process will be to take fifteen minute exterior measurements at each of the four to six locations using an A-weighted filter. The measurement process will be repeated once more for each location using a C-Weighted filter.

During the measurement period, a log should be kept that notes the start time, end time, and date of the procedure. In addition, the major sound sources should be listed as they are heard by the measurer with the corresponding time written next to the description. At the end of the measurement session at each location, there should be a short summary that describes any unusual sources of sound such as airplanes or barking dogs, any unusual weather patterns, as well as any other observation that the measurer deems important.

APPENDIX G

CLASSROOM MEASUREMENTS

Classroom Measurements According to ANSI S12.60-2002

Selecting Which Classrooms to sample:

According to ANSA, not every classroom needs to be sampled in a school. The number of classrooms that is sampled depends on what the goal of the sampling is. However, like any sample, the results should be representative of the population, or in this case, the classrooms of the school. If the desire is to measure the areas that are most likely to have the highest sound level readings, then the classrooms to be evaluated should be those that are close to internal noise sources or external noise sources.

Necessary Parameters for Measuring the Background Noise Levels of a Classroom (ANSI)

Classrooms should be measured for background noise levels when the surrounding classrooms are unoccupied. They should be measured when external noises are the loudest, and while all HVAC systems are turned on. It is important to note that any systems in a classroom that may produce mechanical noise should be turned off. Object such as fans and other devices should no be operating when the measurements are being taken.

Necessary Parameters for Measuring the Background Noise Levels of a Classroom)

The background noise levels for the second method of measurement should be taken during the time when external noises are the loudest. However, in this method, all adjacent classrooms should be in cession. In addition, mechanical noise sources that are present in the classroom on a daily basis and operate for more than 50 percent of the time the class is in session should be turned on. If the classroom noise levels using this method are three decibels higher than in the other method, further effort should be invested into controlling mechanical noises in classrooms as well as noises from other classrooms (ANSI, 2002).

Measuring the Room

The first measurements that should be taken in a classroom are as follows from (ANSI, 2002):

1) The location of HVAC components should be noted
2) The position of the windows and the doors, along with their dimensions
3) The height and locations of partitions that may exist in the classroom

These measurements are accounted for in the classroom observations that are listen in appendix G.

Required Instrumentation for Testing

The sound level meters should have a frequency ratings of A, and C. They should also be capable of time averaging or SLOW time-weighting calculations. In addition to the sound level meter, an acoustical calibrator should be provided that complies with the selected sound level meter. Both the sound level meter and the acoustical calibrator should be certified and guaranteed to be calibrated properly.

Method for Selecting Measurement Locations within a Classroom

In order to receive an optimum set of measurements, a maximum of six locations should be collected within each classroom. The locations should all be within the customary listening area (ANSI, 2002), or the areas where students are present when listening to a teacher in class. These areas should be more than 1m from a wall or other large surface. The loudest of the selected areas is named the "key location". The method for determining the key location is to simply take quick sound level measurements while moving around the room. The other areas are opposite the key location and are distributed symmetrically from the key location. In addition, the measurement height must be determined by the age of the students (ANSI, 2002).

The next step in measuring the background noise is to determine what type of noise is present in the classroom. There are two classes of background noise as defined by ANSI. If the sound level readings, taken at thirty second intervals, have less than a three decibel difference from the highest and lowest sound levels, then the background noise can be declared steady. If there is more than a three decibel difference, then the background noise should be declared unsteady.

Method for Measuring Steady Background Noise

If the background noise level is determined to be steady, then a thirty second measurement from each location can be substituted for the one hour average that determined the ANSI criteria. The measurements can be done on either type of sound level meter as specified above. In addition to an A-weighted reading, a C-weighted reading should also be performed at the key location.

Method for Measuring Unsteady Background Noise

In the case of unsteady background noise, the measurement period should be a full, time-averaged reading. Non-typical noises that occur during the measurement period should be noted, so that drastic increase in the sound levels can be explained.

APPENDIX H

TEACHER SURVEY

Teachers: Please circle one answer for each question

1. What grade do you teach?   1 2 3 4 5

2. While you are in your classroom, can you hear noise from outside of the building?
Yes No

3. What do you hear the most? Car Truck Train Motorcycle Plane Music People

4. Do you hear anything else outside? Yes No

5. Do you feel that you are trying to talk over the outdoor noises? Yes No

6. Do you hear noises coming from other classrooms? Yes No

7. If so what are the sources? Teachers Students Visitors Chairs or Desks

8. Do you feel that you are trying to talk over these indoors noises? Yes No

9. In general, how loud would you rate the noise level in your classroom?
(lowest) 1 2 3 4 5 6 7 8 9 10 (highest)

10. How much does your voice echo when you are lecturing?
(none) 1 2 3 4 5 6 7 8 9 10 (a lot)

11. Do you fell that echoes make conversing with students difficult? Yes   No

12. If more than one person is talking, do you have difficulty understanding the conversation? Yes No

APPENDIX I

QUESTIONS FOR TEACHERS

1. Throughout the school day, do you hear noises that you find distracting?

2. Could you describe some of these noises?

3. Do you feel that the distracting noises you hear come more from inside the building or outside the building?

4. During times that noise is very loud; do you find it hard to keep the attention of students?

5. During these noisy times, does it appear the students have a harder time concentrating on their work?

6. Please explain how noise echoes in your classroom and how, if at all, you compensate for it.

APÉNDICE J

CUESTIONARIO PARA LOS MAESTROS

Maestros: Por favor haga un círculo alrededor de la contestación más correcta

1. ¿A qué grado pertenece?   1 2 3 4 5 6 7 8 9 10 11 12

2. ¿Mientras esta en clase, puede oír ruidos de afuera del edificio?
   ____ Si   ____No

3. ¿Qué produce la mayoría de los ruidos? Use números para establecer el orden. 1 el más importante y 7 el menos
   _____Carro _____Guagua _____Tren _____Motocicleta _____Avión
   _____Música _____Seres Humanos

4. ¿Puede oír otros ruidos de afuera del salón ___Si ____No

5. ¿Tiene que hablar más alto que los ruidos de afuera para que lo entiendan? _____Si ____No

6. ¿Puede oír ruidos de clases en otros salones? ____Si ____No

7. ¿Si usted contestó "si" por la pregunta pasada – quien o qué hace la mayoría de los ruidos?

_____Maestros _____Estudiantes _____Visitantes _____Sillas _____Otra

8. ¿Cree que es necesario que usted hablar más alto que los ruidos interiores?
   _____Si ____No

9. ¿En general, cuál es el nivel de ruido en su clase? Circule la contestación
   (más bajo) 1 2 3 4 5 6 7 8 9 10 (más alto)

10. ¿Cuánto su voz repite cuando usted está dando una conferencia?
    (ningunos) 1 2 3 4 5 6 7 8 9 10 (mucho)

11. ¿Usted se cayó que los ecos hacen conversando con los estudiantes difícil? Sí No

12. ¿Si más de una persona está hablando, usted tiene dificultad el entender de la conversación? Sí No

APÉNDICE K

PREGUNTAS PARA LOS MAESTROS

1. ¿Durante el día, cuando esta en la escuela, usted oye ruidos que son una distracción?

2. ¿Puede describir estos ruidos?

3. ¿Se parece como los ruidos son interiores o exteriores?

4. ¿Cuando los ruidos son altos en clase, considera que los estudiantes se pueden concentrar en usted y escucharle?

5. ¿Cuando los ruidos son altos en clase, considera que los estudiantes tienen dificultades concentrándose en sus tareas?

6. Explique por favor cómo el ruido se reproduce en su sala de clase y cómo, si en todos, usted compensa por él.

APPENDIX L

INTERVIEWS

Jorge Rocafort, Acoustic Engineer at the University of Puerto Rico 3/15/07

Does our equipment perform sound measurements that will be credible?

Is our methodology reasonable?

Will it provide credible results?

Can we use formulas to calculate reverberation time?

- There are between fifteen thousand and sixteen thousand public schools on the island of Puerto Rico
- There is an Acoustical Society of Mechanical Standards on Puerto Rico.
- Wes should take simultaneous measurements of indoor and outdoor noise
- Take measurements in different settings
- Some of his students are performing sound tests on the Route 66 corridor, which is a new expressway that affects two schools right near it
- We should consider taking one of his students who is studying noise with us to the schools where we perform sound tests
- Twenty-five to 40 percent of reverberation time is changed by the number of students in the classroom
- In order to test reverberation time, we should clap and use a meter to determine how long it takes for the sound from the clap to dissipate
- If possible, we should borrow equipment from the Environmental Quality Board to perform the sound measurements

- We need to have credible equipment, an A-weighted level and we need to perform a complete analysis of our data
- For reverberation time we can sketch out the classroom, dimension it and use formulas; but if we want to formalize our data we should use an instrument.

Antonio Ríos, National Recycling Coalition Executive
3/23/07

Do you have any information regarding recycling companies that will help us?

What happens with recycled tires?

What happens with other recycled materials?

If we designed sound reducing material, do you think there is a market for it?

- He provided us with a copy of a case study regarding recycling in different municipalities and towns
- Tires are either burnt here, some are recycled, and some are sent to the United States, South America and Europe
- The case study provides us with contact information about all of the different recycling companies on the island
- The study is broken up into categories of where the landfills and recycling companies are located
- He also informed of that there are information packets that provide incentives for recycling
- Currently most recyclable material gets exported, but in the end he feels that it should be done on the island
- The main form of transportation on Puerto Rico is by truck, while in the United States it is shipped using trains, which is very expensive
- If we market a design, it will be popular and it can be sold and marketed
- Currently, recycled tires are used for playgrounds and car stops in parking lots
- Recycled plastic is used to make floor brushes and plant pots.

Dr. Sergei Caporali, Industrial Engineer at the University of Puerto Rico
4/17/07

Please tell us a little about what study you have been performing.

Do you have any data you can show to us?

Do you think that reverberation is a big problem?

Do you have any data from teacher evaluations?

Does over dampening help reduce noise and reverberation?

- He started his survey eight to ten months ago
- Includes taking noise measurements of several professions including teachers, police officers, tollbooth collectors, garbage collectors, and landscapers
- Example of a police officer
    - six hours of exposure
    - 9 feet from expressway 81.56 dBA
    - 600 feet from expressway 54.61 dBA
    - All of this noise is from the environment
- Example of tollbooth collector
    - six hours of exposure
    - 82.43 dBA
- Example of teacher in a classroom
    - Empty classroom
        - 74.33 dBA on day 1 by the street
        - 76.73 dBA on day 2
    - Classroom with professor speaking

        - 86.71 dBA on day 1

- Intelligibility is very important when it comes to students learning
- Noise problems are different in Puerto Rico than the United States because of the cultural differences and construction of schools is different
- It is not only important that the levels are higher than the standards because there are different factors and limitations of the standards
- It is difficult to prove a hypothesis with a big variance on ones data range
- If we find material, companies, and cost he would be interested in bringing this project further
- It would be helpful to quantify cost per square foot to manufacture and install
- We need to prove that it will be profitable and get the Hearing Conservation Program to possibly invest
- Opportunity cost is very important
    - Determine cost of current equipment
    - Determine cost of your equipment
    - Compare with other investment opportunities
    - Minimize cost
- He has no surveys from teachers for the perception of noise
    - Project will be characterized towards the characterizing of noise in classrooms
- He broke his study into four different phases
    - Quantify exposure
        - 8 hour imagery

        - Frequency analysis
        - 8 hour carbon monoxide exposure
            - Carbon monoxide increases hearing loss
    - Characterization of hearing equity
        - Sources of noise pollution
        - 5 professional areas of study
    - Analyze exposure data
        - Use forecast models
        - Quantify exposure through years the employee has been working
    - Mitigation and control strategies
        - Economic feasibility
- So far he has collected 75 man days of data for phase 1
- Showed us some graphical data from teachers
    - Noise level got as loud as 100 dBA
    - What is the impact on knowledge transfer?
    - He has not performed health effect measurements
    - The noise problem is island wide
- Over dampening classrooms will help, but it will only reduce the noise problem, it will not completely solve it

Eduardo Velazquez, Lead Engineer at REMA
4/23/07

How much weight in waste fiber is produced? (Any units that are easily available to you- we will convert if we need to)

- REMA produces 40 cubic yards of fiber per day

What color is the majority of the waste fiber?

- The majority of the fibers are gray

Is there dirt or other impurities in the waste fiber that would need to be removed before it could be used for other purposes?

- There is dust and other impurities in the fibers
- The tire and polyester mix approximately 15 to 20 percent polyester

Do you think bleaching and rinsing the fibers would remove any dirt and unwanted color? (We would like white fibers for the bonding process)

- There is a $25,000 machine that can clean the fibers by using air and filters

What is an average fiber diameter of a waste fiber? (Any units)

- N/A

What is the percentage of fibers that are in the fiber waste?

- Approximately 10 percent

Are there any materials or chemicals in the waste fibers that could be considered as a health concern?

- No there are none

What does REMA currently do with the waste fibers?

What has REMA done with the fibers in the past?

- They have gave them to Fortiflex
- Fortiflex only had too pay for freight

If REMA ships the fibers, how are they packaged?

- N/A

How much does REMA charge a company that wants to buy the fibers? (price/ weight)

- The companies will only have too pay freight since REMA wants to show that they use the fibers
- There is 40 percent more tire recycling that they could have if they can recycle all of the tire materials
- They have the potential to recycle 100 percent of the tires on the Island but the Government lets other companies use tires for other purposes

Do you know of any companies in Puerto Rico that might be interested in manufacturing products that are made out of recycled polyester?

- N/A

Do you think a demand for polyester fibers will increase the demand for recycled tires, in general, or will the demand for rubber always determine how much waste is produced?

- No, tires will always be the limiting factor

Could you list some steps that you think might be necessary in manufacturing ceiling tiles that are made out of waste fibers i.e. a) grinding b) bleaching and rinsing c) drying and thermal bonding d) cutting e) applying fire-proofing f) dry and ship

- N/A

APPENDIX M

SOUND RECORDINGS CHART

Date:
School:
Location:
Recorder:

	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5	Reading 6
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

APPENDIX N

TEACHER FREE RESPONSE

This appendix contains some of the most helpful free response comments from the teachers in response to our question "During times that noise is very loud; do you find it hard to keep the attention of students?"

1. A los estudiantes se les dificulta concentrarse cuando no hay ruido; asi que, cuando hay ruido se concentran menos.
2. Interfieren demasiado y tengo que subir demasiado el tono de voz.
3. Hasta que ellos no están si silencio y atendiendo a la maestra, no inicio la clase.
4. Cuanto hay ruidos innecesarios fuera del salón los estudiantes pierden la concentración y se hace muy difícil recupérala.
5. Dependiendo el ruido los estudiantes no pueden escuchar o entender la clase.
6. A veces; si el ruido es muy fuerte no se puede continuar.
7. No pueden concentrarse y no escuchan bien.
8. Es buen difícil. Ya lo he aprendido a manejar, pero no es lo ideal.
9. Los estudiantes no pueden concentrarse y es mucho más difícil el aprovechamiento académico.
10. Definitivamente, no puede concentrarse porque el ruido interfiere con el proceso de enseñarse.

APPENDIX O

POLYESTER AS A SOUND ABSORBER

Summary of (Joo & Lee, 2003) and (Lin & Lou, 2005)

The following appendix briefly describes previous research that proves that polyester is an excellent sound absorber. The section shows the result of two studies that were completed in Asia using waste fibers from textile manufacturers. The results of the study are summarized in tables that show the effectiveness of the material as a sound absorber. Both of the studies assembled their acoustical tiles by using thermal bonding methods.

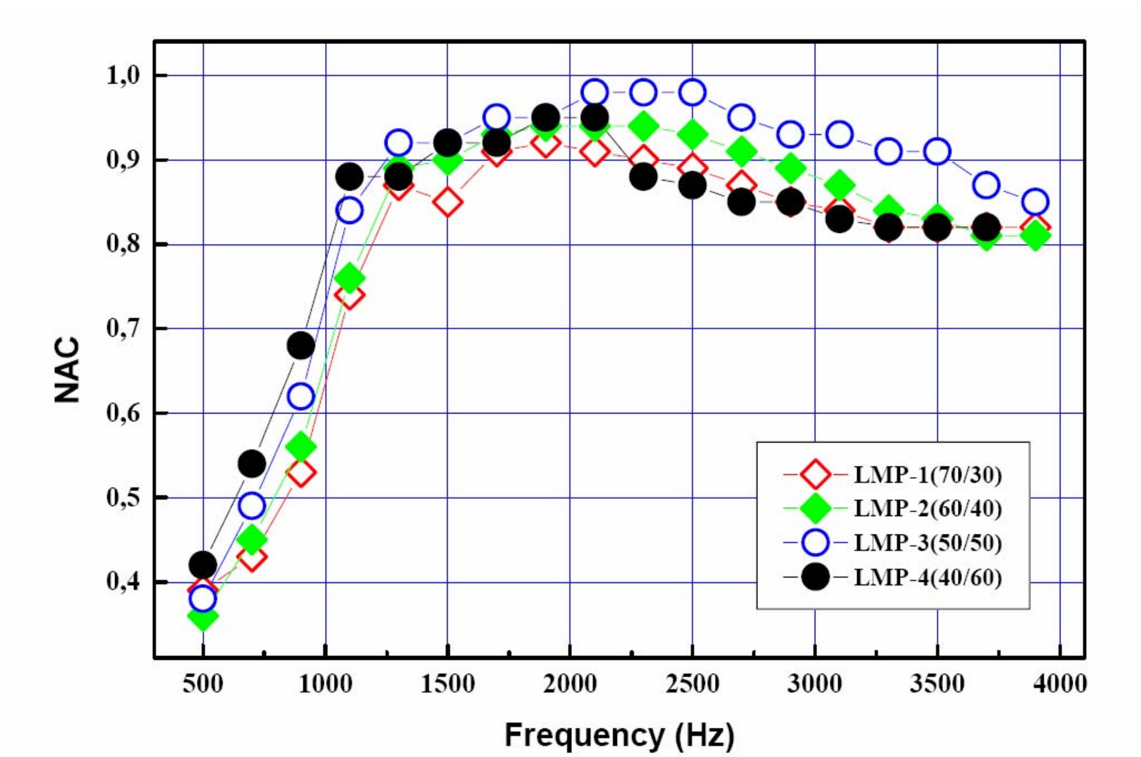

Figure A: Absorption Coefficient for Acoustical Polyester Tiles (Joo & Lee, 2003)

Figure A show how effective that acoustical tiles made out of polyester are. The y axis of the graph shows the NAC or average absorption coefficients and the x- axis represents the frequency of the sound wave.

Thickness (mm)	Frequency (Hz)						
	α_{125}	α_{250}	α_{500}	α_{1000}	α_{2000}	α_{4000}	$\bar{\alpha}$
17	0.10	0.19	0.17	0.37	0.86	0.91	0.43
34	0.10	0.39	0.35	0.87	0.90	0.92	0.59
51	0.10	0.12	0.67	0.97	0.85	0.95	0.61
68	0.24	0.45	0.90	0.85	0.93	0.94	0.72

Figure B: NRC Rating for Acoustical Polyester Tiles (Lin & Lou, 2005)

Figure B shows the average absorption coefficients that were measured in a study performed by (Lin & Lou, 2005). The figure shows that the average absorption increases by increasing the thickness of the acoustical tile.

APPENDIX P

RECOMMENDATIONS FOR PROSPECTIVE MANUFACTURERS OF ACOUSTICAL CEILING TILES

First and foremost, we recommend that any prospective manufacturer hire a lawyer to investigate any legal aspect of our idea. He or she should investigate any patents that may control the production or manufacture of these materials. Any manufacturer would want to guarantee that they could develop our idea further before they invest any more money in the project.

Secondly, ***we recommend that the local company invest more money in the research and development of our idea***. The data that we gathered concerned the results from the manufacture of acoustical ceiling tiles from similar materials. However, we were not expert industrial engineers or material scientists at the time this report was written. Therefore, any local manufacturer should hire a material scientist that could confirm our results before they invest in manufacturing equipment. Also, an interested manufacturer should hire an industrial engineer to describe exactly what machinery should be purchased for the manufacturing process. Lastly, the prospective manufacturer must guarantee that the acoustical ceiling tiles will comply with all international fire and building codes. ***We recommend that the manufacturer contacts a Fire Protection Engineering firm for consultation on this subject***.

Thirdly, the prospective manufacturer should sign a contract with REMA that outlines how much material they are going to be able to receive from the tire recycling process over a ten year period and how much they are going to be charged. Currently, REMA does not charge for the fibers since they must dispose of them before they can increase their production of crumb rubber. However, in the future they may decide to start charging for the fibers. This increase in the raw material price will increase the cost per tile if the manufacturer will not accept a decrease in profit. Our group believes that the main appeal of using waste fibers is the low-cost that is associated with the tiles. For this reason, ***we recommend that any prospective manufacturer negotiates a fixed price for the waste polyester***. In addition, the contract should guarantee that no other company will be able to buy the waste fibers since the prospective manufacturer will want to use all of the waste fibers produced by REMA each year.

Next, ***we recommend that the prospective manufacturer invests time and money to determine the demand for the acoustical ceiling tiles***. As the results of our cost analysis show, a year's production of acoustical ceiling tiles could be ordered in two or three construction contracts (See Results: Sound Absorbing Material). ***Our group recommends that a prospective manufacturer determine exactly how many contracts they will need to obtain per year in order to maximize their profit and minimize their inventory***. If they believe that there is a sufficient market on the Island or anywhere else in the world, then we recommend that the prospective manufacturer buy the required machinery and starts production.

Lastly, ***we recommend that the acoustical tile manufacturer continue to research different recyclable materials that could be used in the production of ceiling tiles***. One example of another material that can be used for the production of ceiling tiles is cellulose. ***We recommend that a manufacturer consider using this material, and***

other, as a means of increasing their profit and decreasing the amount of waste materials that exist on the island of Puerto Rico.

APPENDIX Q

COMMERCIALLY AVAILABLE ACOUSTICAL TREATMENTS

After all of our research on noise in classrooms, we have concluded that reducing the noise levels in schools to below forty decibels is possible no matter what types of noise sources surround a school. The problem is that these solutions can often be costly enough to make them impossible. As far as reducing the amount of noise that enters classrooms is concerned, Puerto Rico has one major advantage and one major disadvantage. The advantage is that most buildings are built with concrete, which is one of the best materials for decreasing the amount of sound that is transmitted through a partition (STC Rating, 2004). The disadvantage is that the high temperatures on the island require the use of natural ventilation or air conditioning. Every school that we visited used natural ventilation, or open windows, as the primary method to cool classrooms. The problem with this method of cooling, as far as sound is concerned, is that outdoor noises can easily pass through the open windows. The benefit of open windows is the fact that reverberation is reduced.

If the Department of Education were to eliminate the problem of excess noise and reverberation using commercially available acoustical treatments, the following are the steps it would have to take:

First, ***we recommend that schools completely seal any windows that are in classrooms.*** The best way for schools to seal any of the existing windows would be for them to use double-pane glass that is completely sealed to the window opening. However, if any other material is used to seal the windows in a classroom, the material should completely cover any openings in the window area. Secondly, ***we recommend that schools install***

central air conditioning systems that require no moving parts to be located within a classroom. We recommend that schools follow the installation procedures that are specified in ANSI S12.60-2002. At a minimum, schools should ensure to use only the quietest possible air conditioning units that have the condenser located outside of the building. Third, since the windows will be closed, ***we recommend that schools add enough acoustical tiles to the ceiling of the rooms in order to reduce the reverberation time to at least .6 seconds.***