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AB-10-C037: Effects of noise from building mechanical systems on elementary school student achievement

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ABSTRACT

This project seeks to determine what relationship, if any, exists between background noise levels in elementary classrooms due to the building mechanical systems and student performance on achievement tests. Previous research in classroom acoustics has clearly identified that lower background noise levels result in higher speech intelligibility which is crucial for the learning process; however, there is a lack of data correlating lower noise levels to improved student achievement scores. For this study, background noise level measurements were made in 14 elementary schools in a public school system in Council Bluffs, Iowa, USA. The measurements were made in unoccupied classrooms with the central building mechanical systems activated. Second and fourth-grade classrooms were included in the study, which typically contain 7 to 8 and 9 to 10 year-old students, respectively. The unoccupied noise levels measured in the analyzed classrooms range from 36 – 50 dBA, none of which meets the background noise level recommendation of 35 dBA or less specified for classrooms in ANSI S12.60-2002(R2009). These measured background noise levels have been correlated to reading comprehension and math standardized achievement test scores from students in the surveyed classrooms. Poverty rates were used as a control variable for the correlation analyses to factor out some of the socio-economic differences among the students. ANOVA and regression analyses were also performed to determine if learning for the younger and older students was impacted similarly by mechanical system noise and what background noise level should be attained in classrooms to meet state learning achievement goals. The results from this study show that, for the elementary school system tested, lower student reading comprehension scores were significantly related to higher background noise levels from building mechanical systems.

INTRODUCTION

Good indoor environmental quality is important for the comfort and learning of

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school children (Mendell and Heath 2005). Various types of building mechanical systems are used to help provide such climate-controlled environments. However, the impacts of the mechanical systems on the acoustical environments should also be considered when designing learning spaces. It has been shown that speech intelligibility is dramatically reduced by higher levels of background noise, particularly for young listeners (Elliott 1979; Bradley and Sato 2008). Yet, high background noise levels have been documented in several existing elementary schools (Knecht et al. 2002; Shield and Dockrell 2004; Choi and McPherson 2005). Other research indicates that student achievement and performance may be negatively impacted by high levels of occupied background noise (Dockrell and Shield 2006; Shield and Dockrell 2008). Although there is some evidence that higher unoccupied noise levels lead to higher occupied noise levels (Sato and Bradley 2008), more work is necessary to determine the effects of unoccupied background noise on student achievement and learning, since unoccupied background noise levels are typically specified in the design and construction phases of buildings. Currently, there are building standards that specify a maximum unoccupied background noise level of 35 dBA for classrooms, in accordance with the ANSI S12.60 Standard on classroom acoustics (ANSI 2002 (R2009)). This level was determined based on requirements for appropriate speech intelligibility, but research is lacking that indicates if meeting this standard translates into measurable student achievement gains.

This study seeks to determine what levels of unoccupied background noise impact student learning by assessing the relationship between measured unoccupied background noise levels and standardized student achievement scores from students in the surveyed classrooms. This research was conducted in 14 elementary schools in a midwestern United States public school system. Acoustical measurements, including unoccupied background noise level and reverberation time, were made in second and fourth-grade classrooms in these schools and correlated to the student achievement test results.

METHODS

Site visits were conducted in 58 total second and fourth-grade classrooms in the public school system in Council Bluffs, Iowa, USA, from April – June 2009. This encompassed all of the second and fourth-grade classrooms, typically containing 7 to 8 and 9 to 10 year-old students, respectively, in the school system during the 2008 – 2009 academic year.

Site Visit Procedures

During each site visit, detailed notes and photographs were taken to record the room dimensions, building materials, room furnishings, and noise sources. Acoustical measurements were gathered in each unoccupied classroom. Prior to the start of each acoustical measurement, the windows and doors to exterior and adjacent spaces were closed.

Classroom Descriptions

All of the classrooms had a traditional, closed floor plan design. Typical room materials included a thin carpet on the floor, acoustical ceiling tile, and either gypsum board or concrete masonry unit walls. Many of the classrooms had several large windows facing the exterior. The rooms were furnished with desks, shelves, and cabinets, with tack-boards and chalkboards lining the walls.

Most of the rooms were temperature controlled by central mechanical systems, with regularly spaced overhead diffusers supplying the air for cooling. The return air grille was often located near the classroom entrance. The temperature was set in each room by a wall-mounted control unit, which typically had set-points ranging from 70 - 76°F (21 - 24°C). However, six of the classrooms had window air-conditioning units supplying the cool air, instead of a central cooling system. In these classrooms, the air-conditioning units were activated by the teachers as needed for cooling the space.

Acoustical Measurements

Background noise level (BNL) and reverberation time (RT) measurements were taken in each unoccupied classroom. As all of the RT measurements were lower than the 0.6 seconds recommended by ANSI S12.60 (ANSI 2002 (R2009)) and were not found to be significantly related to student achievement scores, further discussion of the RT results will not be presented in this paper.

Prior to the start of each BNL measurement, the mechanical systems were activated in the cooling mode whenever possible. BNL measurements were not obtained with the mechanical systems operating in the heating mode. The BNL was recorded at the center of each space using a Larson Davis 824 sound level meter. The meter was mounted on a tripod, with the microphone located approximately 3.7 ft (1.1 m) above the ground. The BNL was recorded in additional locations when the background noise in the space was not approximately uniform, as subjectively determined by the measurement personnel. When additional BNL measurements were taken, the energy average of the BNL in each position was used to characterize the background noise of the space. The BNL was recorded over a five minute continuous time period. The content and duration of noise sources occurring during the BNL measurement time were noted.

Standardized Achievement Tests

Results from the Iowa Test of Basic Skills administered to the students during the 2008 – 2009 academic year were gathered. Available scores from the reading comprehension subject area and math subject area, which included concepts, estimation, problem solving, and data analysis, were compiled. The results were reported as an average percentage of proficient students per grade level per school. The percent of proficient students is determined by the state of Iowa for each school year, and was set to be the percent of students scoring above the 41st percentile for the 2008 – 2009 academic year. Poverty rates for each school were used as a demographic variable to control for some of the socio-economic differences between schools. This was reported as the percent of students who lived in households below a certain income level, averaged per school.

RESULTS

Background Noise Level

The results from the BNL measurements for each classroom are shown in Figure 1. This figure shows the A-weighted equivalent sound level (L_{Aeq}) over the five minute measurement time period for all of the classrooms.

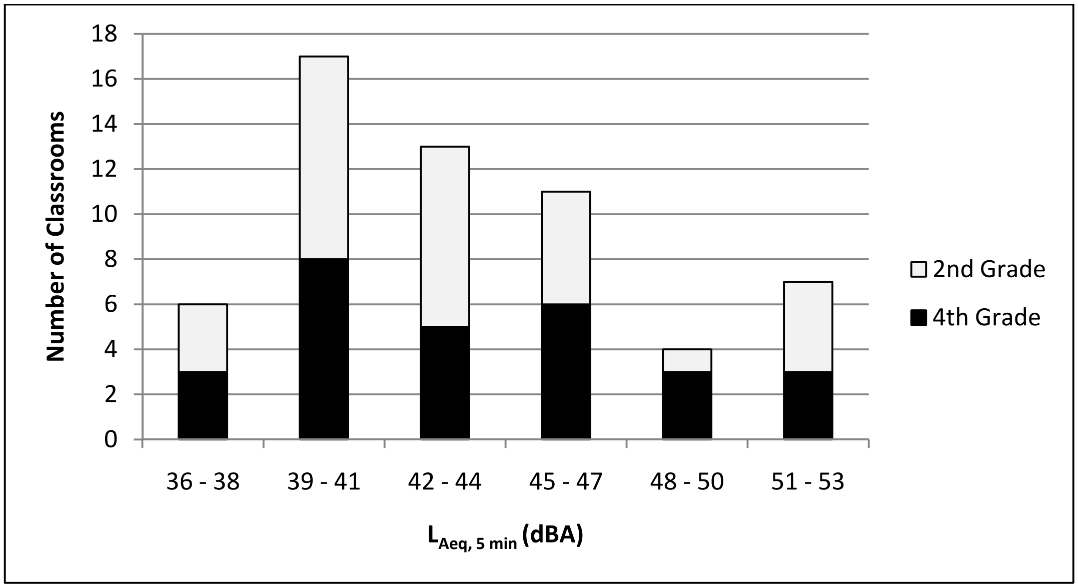

Figure 1 *A-weighted equivalent sound levels for all of the classrooms measured. This includes spaces with the BNL measured with central mechanical system activated (50 classrooms), with the central mechanical system deactivated (2 classrooms), and with the window air-conditioning units activated when present (6 classrooms).*

The results from the BNL measurements averaged per grade level per school are shown in Figure 2. This figure shows the L_{Aeq} over the five minute measurement time period for 11 of the 14 schools included in the study. Results from three of the schools have been omitted, since these included classrooms with window air-conditioning units that were activated and central mechanical systems that were deactivated for the measurements. The bars show the range in BNL about the average value for all of the classrooms at each grade level in each school.

Standardized Achievement Tests

The results from the standardized student achievement tests, reported as the percentage of students at each grade level in each school scoring above the 41st percentile are shown in Table 1. The average poverty rates for each school are also provided in Table 1. The 11 schools shown in Table 1 are the same schools shown in Figure 2, which had consistent mechanical system conditions for all of the BNL measurements. The state of Iowa sets the minimum percentage of proficient students who should meet the state achievement trajectory at the fourth-grade level for each academic year. For 2008 – 2009, the fourth-grade state trajectory for reading comprehension was 76% proficient and the state trajectory for math was 74.7% proficient.

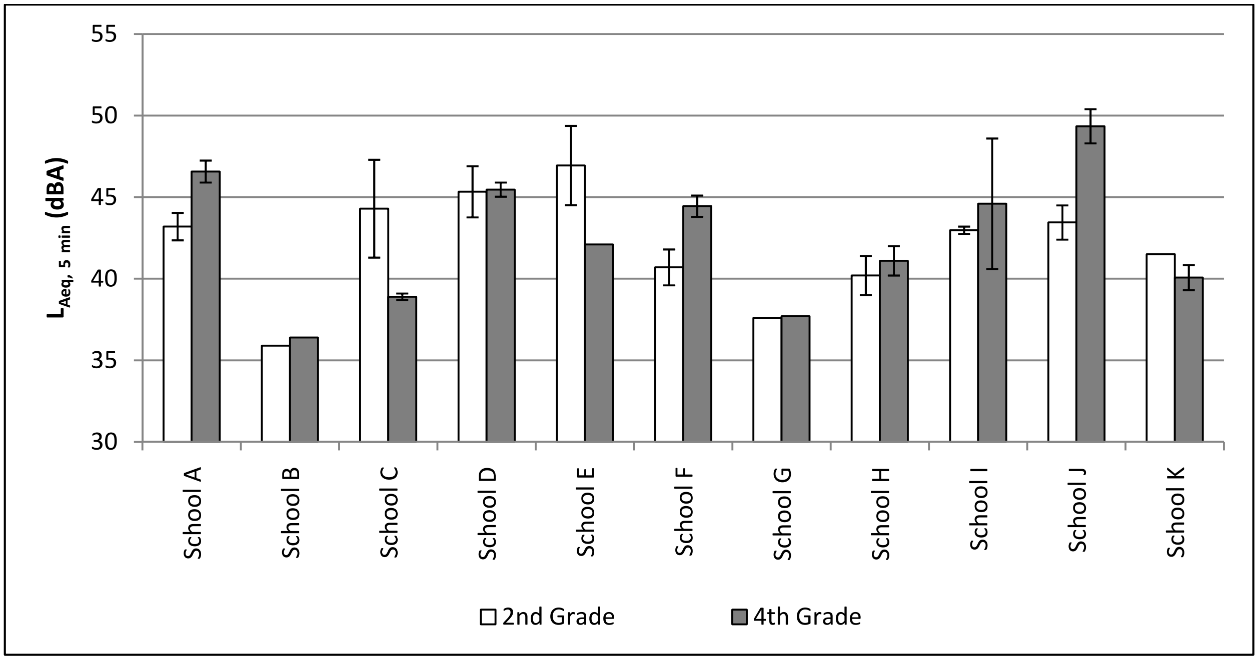

Figure 2 *A-weighted equivalent sound levels for 11 of the schools, all with consistent mechanical system conditions for the BNL measurements (BNL measured with central mechanical system activated). The bars show the range in BNL about the average value for all classrooms at each grade level in each school.*

DATA ANALYSES

Statistical analyses were performed on the data to evaluate impacts of the classroom BNLs on the student achievement scores. Since the standardized achievement test results were not available on a per classroom basis, the average BNL conditions per grade level per school were compared to the average reading comprehension and math standardized achievement scores per grade level per school. Only the schools (11 total) with the central mechanical system operating during the measurements were included in the BNL statistical analyses.

To determine if parametric statistical tests should be used, the distributions of all of the data sets were tested for normality. The Kolmogorov-Smirnov tests for normality indicated that none of the data distributions are significantly different from normal distributions. Consequently, parametric statistical tests including Pearson correlations, semi-partial correlations controlling for poverty rates, analysis of variance (ANOVA), and regressions may be utilized to assess the relationships between the BNL and the standardized student achievement scores. More information on these statistical methods may be found in Field (2000) and Field and Hole (2003).

Table 1. Standardized Student Achievement Scores and Poverty Rates

	Standardized Student Achievement Scores (% Proficient)				
	2nd Grade		4th Grade		
	Reading Comprehension	Math	Reading Comprehension	Math	Poverty Rates
School A	62	42	72	72	77
School B	75	75	100	73	34
School C	73	71	71	73	81
School D	66	59	66	71	63
School E	62	62	84	74	49
School F	59	51	72	84	64
School G	92	62	69	77	72
School H	69	49	78	69	78
School I	78	83	76	76	64
School J	68	66	58	70	75
School K	70	65	66	66	84

As shown in Figure 2, the unoccupied BNLs in the analyzed classrooms range from 36 – 50 dBA, none of which meets the maximum level of 35 dBA recommended in the ANSI S12.60 Standard (ANSI 2002 (R2009)). The zero-order Pearson correlations relating BNL to the standardized achievement scores were calculated, with the only significant relationship occurring between BNL and the reading comprehension student achievement scores ($r = -0.55$, $p < 0.01$), indicating that students' reading comprehension learning ability is negatively impacted by higher unoccupied BNL. When controlling for the effects of poverty rates on the reading comprehension scores, the semi-partial correlation value of -0.49 between BNL and reading comprehension is also significant ($t(19) = -2.55$, $p < 0.05$).

A two-way independent ANOVA, with grade level and BNL as the independent variables and reading comprehension scores as the dependent variable, was conducted to further assess the relationship between BNL and reading comprehension. For the ANOVA, the BNLs were grouped in 3 dBA ranges. The results show that the main effect of grade level on the reading comprehension scores is non-significant ($F(1, 13) = 2.04$, $p > 0.05$), whereas the main effect of BNL on the reading comprehension scores is significant ($F(4, 13) = 3.38$, $p < 0.05$). The interaction effect between grade level and BNL is not significant ($F(3, 13) < 1$, $p > 0.05$), indicating the second and fourth-grade students' reading comprehension scores were impacted similarly by varying BNL.

A scatter plot between BNL and reading comprehension student achievement scores is shown in Figure 3, along with regression lines plotted from models that were calculated to quantify the negative relationship of high BNL on reading comprehension scores for the data sets containing (a) the second-grade classrooms only, (b) the fourth-grade classrooms only, and (c) the combined second and fourth-grade classrooms. The model using the combined second and fourth-grade data set is found to be significant at the .01 level ($F(1,20) = 8.56$, $p < 0.01$), with BNL accounting for 30% of the variance in the reading comprehension scores ($R^2 = 0.30$, $p < 0.01$). The results suggest that in order to meet the minimum state trajectory of having 76% of the fourth-grade students exhibiting proficiency in reading comprehension, the highest acceptable unoccupied BNL predicted by the regression model for the fourth-grade classrooms only is 41 dBA; note that the reading comprehension scores continue to improve as the unoccupied BNL is decreased below 41 dBA, though.

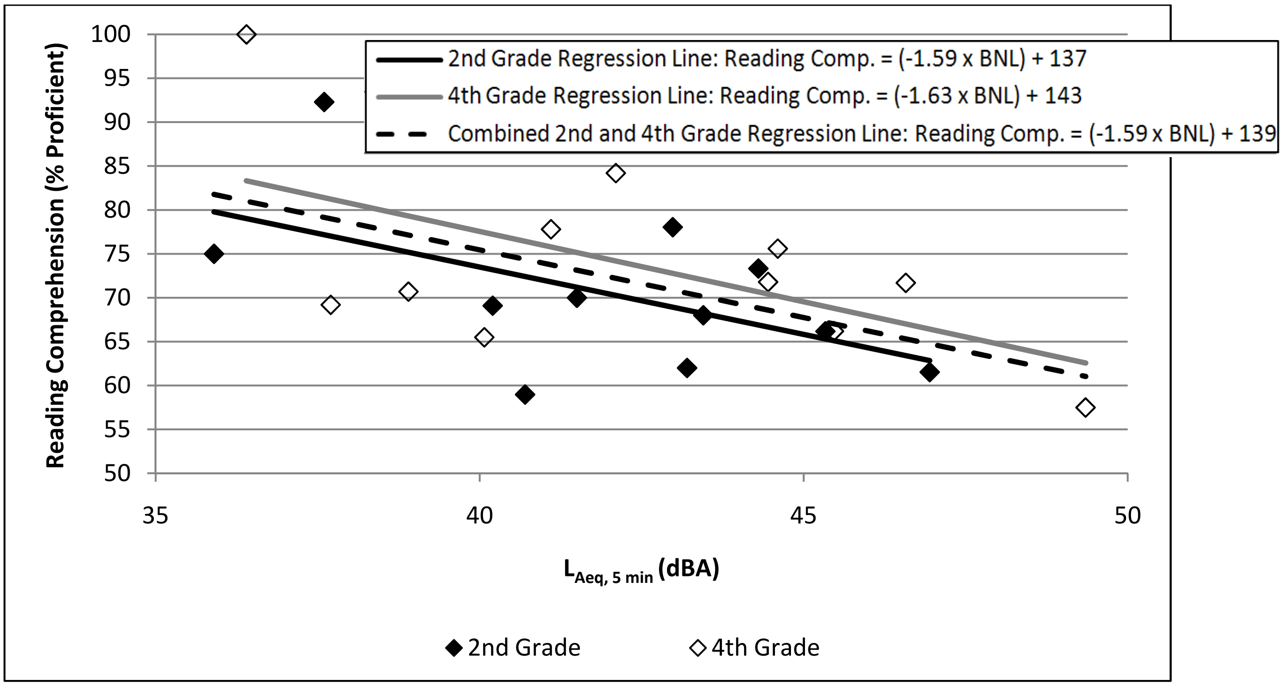

Figure 3*Scatter plot and linear regression lines between unoccupied BNL and reading comprehension scores.*

DISCUSSION AND CONCLUSIONS

The measured acoustical data from second and fourth-grade classrooms in the public school system in Council Bluffs, Iowa, have been compared with the standardized student achievement scores from the Iowa Test of Basic Skills. The results indicate that the unoccupied BNLs are not significantly correlated to the math student achievement scores, but they are significantly correlated to the reading comprehension student achievement scores even when controlling for poverty rates. In general, higher unoccupied background noise levels are related to lower reading comprehension student achievement scores. The learning processes for math may be more visual, problem-solving based, rather than verbal, which may explain why the reading comprehension scores are detrimentally impacted by higher BNL, whereas the math scores are not. The significant relationship between unoccupied BNLs and reading comprehension student achievement scores supports previous research, which found that occupied noise levels are impacted by unoccupied noise levels (Sato and Bradley 2008).

Since the central mechanical systems were activated and comprising the majority of the background noise content during the measurements, this indicates that mechanical systems should be designed with lower background noise levels in elementary school classrooms to optimize student learning and achievement. This study shows that the highest allowable unoccupied BNL to meet the minimum acceptable reading comprehension student achievement in Iowa is 41 dBA. However, more research is necessary to determine the exact unoccupied background noise levels that should be specified in building standards. Continuing research in this area should include measurements in a larger sample of classrooms with the mechanical systems operating in various modes.

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