PROCEEDINGS of the
23rd International Congress on Acoustics

9 to 13 September 2019 in Aachen, Germany

Exploring the effect of ventilation type on the acoustics of primary and secondary school classrooms

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Abstract
To better understand the effect of indoor environmental conditions on primary and secondary student performance, measurements over six school days were logged in each of 220 classrooms at schools in the midwestern region of the United States. Results from statistical analyses demonstrate the effects of classroom conditions on student achievement scores. Specifically, structural equation modeling has been used to determine the effects of classroom speech levels, non-speech levels, and room reverberation conditions on math and reading achievement, while controlling for student demographics. Information regarding heating, ventilation and air conditioning (HVAC) system types was also gathered in each classroom. The focus of this paper is to report on the correlation between HVAC system type and the measured speech or non-speech levels in classrooms during the school day. Additionally the correlations between measured acoustic and indoor air quality parameters over time are presented, with specific regard to how HVAC system type might affect the correlations.

Keywords: classrooms, noise, ventilation systems

1 INTRODUCTION

Primary and secondary school students spend significant amounts of time in classrooms. Much work has been done in exploring the effect of noise on building occupants. Both room acoustic characteristics and background noise levels contribute to the speech intelligibility of a room, a crucial factor in determining effective communication, such as conversations or instruction. In classrooms specifically, studies have found that increased noise in the classroom is associated with lower achievement in students (1,2).

It is known that ventilation systems within classrooms contribute to background noise levels. Heating, ventilation, and air conditioning (HVAC) system components have noise specs and ratings, but performance can vary based on installation, age, and any number of factors. This study looks at a large sampling of real classrooms of known HVAC system types, observing the noise levels and their relationship with indoor air quality factors.

2 METHODS

To evaluate the indoor environment in primary and secondary schools, 220 classrooms in the midwestern United States were selected for measurement. A variety of measurement were taken in each classroom, including acoustic, indoor air quality, thermal comfort, and lighting measurements. Details of these measurements are discussed in other work within the scope of the grant (3). For this paper, the logged measurements of sound and select indoor air quality parameters will be discussed.

2.1 Sound measurements

Within each classroom, two BSWA 309 Type II sound level meters were deployed for a period of two days, three times within the school year, leading to six school days of logged measurements per classroom. The meters were placed in similar locations within each classrooms, with one in a measurement kit placed near the teacher's desk at the head of the classroom and the other hanging from the ceiling in the classroom. Measurements were taken at 10 second intervals throughout the occupied school day and equivalent continuous

A-weighted levels ($L_A$eq), as well as octave band levels, were collected at each time interval.

During the school day, there were times where speech noises were present, either from teacher instruction or student participation, and times where only background and activity noise were present. In previous work by researchers on this grant, k-means clustering–an unsupervised machine learning technique–was utilized to separate each time interval into one of two categories: active speech or non–speech based on the level and spectral content (4).

2.2 Indoor air quality measurements

On the same days sound level was logged, a variety of indoor air quality measurements were being logged in 5 minute increments. A select few include carbon dioxide (CO_2), fine particulate matter, and coarse particulate matter. Carbon dioxide was measured by several sensors: one in the measurement kit by the teacher's desk, one in or near the supply duct, and a third in or near the return duct. A CO_2 average was calculated for each time increment by taking an average of these three meters. For the particle counts, a counter within the measurement kit took measurements of air particles of difference sizes every 5 minutes. Air particulates smaller than 2.5 μm were considered to be 'fine' particulate matter. Particles between 2.5 and 10 μm are considered to be 'coarse' particulate matter.

2.3 Statistical analysis

Analysis of variance was conducted on the sound levels within each classroom, considering both the speech and non–speech levels. Personnel involved in ventilation system design and installation often have opinions and evidence about system noise levels. The question considered in this analysis is the following: In a real–world sample, is there a significant difference in noise level between different HVAC system types? This question is considered for the occupied classroom, looking first at speech times and second at times where no speech is present in the classroom.

For each classroom, the HVAC system type was noted and three categories were selected, primarily based on the secondary system type. The three categories are as follows:

- Heat Pumps: systems that include a heat pump (n = 104)
- Centralized: systems that stem from centralized components, utilizing air handling units, variable air volume (VAV) boxes, etc (n = 41)
- Unit Ventilators: systems that include a unit ventilator within the classroom (n = 59)

Classrooms with unknown or difficult to characterize systems were eliminated from analysis. Analysis of Variance (ANOVA) was used to determine if the means of the noise values were different between the system types.

Additionally, an analysis of the effect of HVAC system type on the temporal correlation between sound level and indoor air quality measures was considered.

3 RESULTS

For each classroom, an average sound level was calculated for both the speech and non-speech times. For each of the 220 classrooms, the time log of speech or non–speech sound levels for each measurement day were logarithmically averaged, giving each day a single $L_A$eq. These day values were arithmetically averaged by classroom to give a single value per classroom, indicative of a likely sound level that would be experienced in that classroom at any given time.

Both speech sound levels and non–speech sound levels were divided into the three HVAC categories.

Figure 1 shows the histograms of the distributions of average speech levels for each HVAC division. While it is clear that more classrooms fall into the heat pump category than either other category, this is just a byproduct of the sample chosen. The takeaway from these histograms is where the peak of the distribution curve falls, which indicates the average value for that category. For example, for each of the categories, the average speech value falls around 66 dBA.

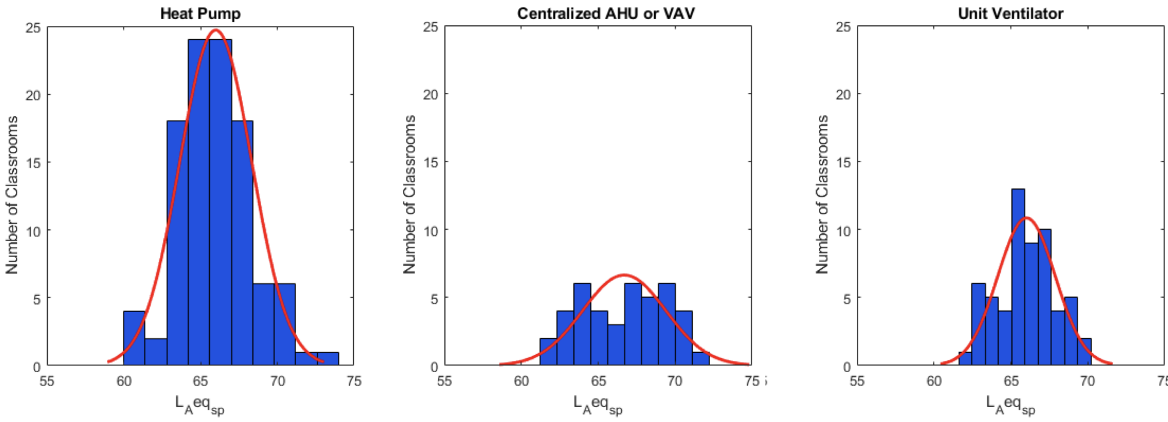

Figure 1. Histograms of the distributions of speech noise levels within a sampling of classrooms (n = 220), divided into three HVAC system types

Figure 2 shows the distributions of non–speech average levels by system type. Here, the differences in the mean values may be more apparent between the categories, especially with the unit ventilators mean value being higher than the other two categories.

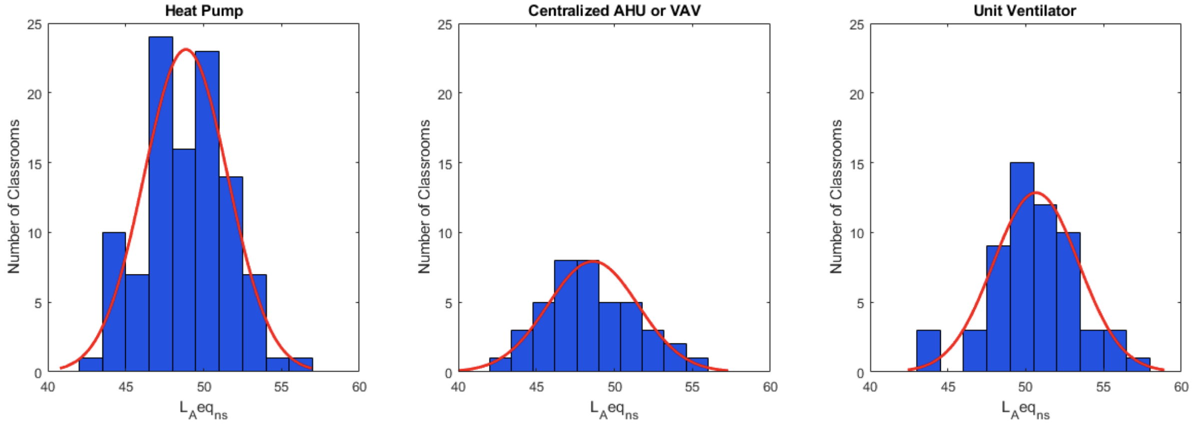

Figure 2. Histograms of the distributions of non–speech noise levels within a sampling of classrooms (n = 220), divided into three HVAC system types

The sound level averages for each category are presented in Table 1. For the average equivalent continuous level for speech times ($L_A eq_{sp}$), all values were near 66 dBA, with centralized systems experiencing the highest levels, at a 66.5 dBA average. For the non–speech average, unit ventilator classrooms averaged the highest levels, at 50.6 dBA, with heat pump and centralized systems averaging 48.7 and 48.4 dBA for non–speech noise, respectively.

Table 1. Average sound levels by system type for speech and non–speech noise within classrooms in dBA

System Type	L_Aeq_{sp}	L_Aeq_{ns}
Heat Pumps	66.1	48.7
Centralized	66.5	48.4
Unit Ventilators	65.9	50.6

3.1 ANOVAs of noise levels

Analysis of variance was conducted on the average speech levels of each classroom by HVAC system type. No difference was found between the means of the speech levels within the classrooms, indicating that the HVAC system type was not significant when determining the sound level during speech times for this sample.

On the other hand, the ANOVA for the non–speech levels was significant for this sample ($p = 0.019$), indicating a difference between the non–speech level means of the three HVAC groupings (see Table 2). Post-hoc tests revealed that classrooms with unit ventilators had significantly higher noise levels than classrooms with heat pumps. No difference was found for the non–speech noise levels between classrooms with centralized systems and classrooms with unit ventilators.

While the difference in means (see Table 1) is small–only around 2 dB–it should be noted that this is not a simple decibel difference, but rather an aggregate difference of a larger sampling, so conclusions should not be drawn regarding just noticeable differences or error propagation without a more in–depth analysis.

Table 2. ANOVA table for non-speech noise divided into HVAC categories

Model	SS	df	MS	F	*p*
Regression	30.558	2	15.279	4.424	.019
Residual	120.885	35	3.454		
Total	151.443	37			

3.2 Correlations by HVAC system type

In order to see how strongly the sound level and indoor air quality variables fluctuated together throughout the day, correlations were drawn for each classroom and each day of measurement. Sound level was logarithmically averaged to go from a 10 second resolution to 5 minute increments and all data underwent temporal statistical de–trending. Discussion of this process and the resulting correlations can be found in previous work (5). Of interest to this topic is the likelihood of classrooms with certain system types to see more significant correlations than others. For the correlations between sound level and CO_2 and sound level and coarse particulate matter, no observable difference was found between the system types. However, for the correlations between sound level and fine particulate matter, unit ventilators were found to experience a higher percentage of significant correlations. Table 3 shows the percentage of significant correlations for each system type, showing that in classrooms with unit ventilators, 58% of observed correlations between L_Aeq and fine particulate matter were statistically significant at the Bonferroni corrected level ($p < 0.00089$).

Table 3. Percentage of significant correlations between fine particulate matter and sound level over time in classrooms by system type

System Type	% Significant
Heat Pumps	23%
Centralized	39%
Unit Ventilators	58%

4 DISCUSSION AND CONCLUSION

An analysis was undertaken to quantify the effect of HVAC system type on the noise levels within a real–world sample of 220 primary and secondary school classroom. While no difference was observed between levels of speech within each classroom, the noise with no speech present was different in classrooms with different system types. Classrooms with unit ventilators were discovered to have quantifiably louder non–speech sound levels than classrooms with heat pumps or centralized systems. No sound level difference was observed between the former two.

Additionally, the temporal variation in fine particulate matter in a room was found be more likely to correlate with the sound level in rooms with unit ventilators, with 58% of cases found to be significant within this category. This is perhaps due to increase in sound level when the units kick on, correlating to the increase in particle matter pulled in from outside while the units function.

Knowing about these relationships helps characterize the complex indoor environment within classrooms, ultimately aiming to inform design decisions. Future work can explore whether ventilation system type directly links to student achievement or comfort.

ACKNOWLEDGEMENTS

Thank you to the many faculty and student researchers on this project. This research was supported by EPA Grant R835633.

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