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# CLASSROOM ACOUSTICS OF MCNEESE STATE UNIVERSITY

Aash Chaudhary and Zhuang Li

*McNeese State University, Department of Chemical, Civil, and Mechanical Engineering, Lake Charles, LA, USA*
*email: zli@mcneese.edu*

Acoustical conditions in a classroom have great impact on speech perception and in student learning. In this research a thorough survey was carried out in 80 unoccupied classrooms of eight different buildings at McNeese State University. Experiments were conducted to measure the reverberation time and ambient sound pressure levels. A portable test platform was developed using a ½” microphone, a USB-based data acquisition device, a laptop computer, and software programmed in LabVIEW. The experiments were designed according to the ISO and American national standards. The software saves raw data to the computer hard drive and presents both the A-weighted and C-weighted sound pressure levels. If a thermostat is available in the classroom, then ambient sound pressure levels were measured in two different conditions, air conditioning on and off, otherwise only one condition was measured. While conducting the experiment, classroom doors were closed at all times to avoid any outside noise or interference. The sound pressure level and reverberation time vary depending on the size, finish of the classroom, building, and floor. The results were analyzed and compared with the American national standards. Statistical analyses were conducted. For most of the classrooms, the sound pressure levels and the reverberation time are higher than the criteria set by the American national standard. Recommendations are provided to improve the classroom acoustics.

**Keywords**: classroom acoustics, background noise level, reverberation time.

## 1. Introduction

Various factors affect a classroom’s acoustical conditions which further affect the speech perception and learning experiences. Background noise and reverberation time (RT) have the most prolific impact on the ability of a student to concentrate as attention is a flexible and adaptive.

In a reverberant space, the reverberation time is normally defined to be the time for the sound pressure level to drop by 60 dB when the sound source is cut off. An adequate RT is needed to achieve liveness of the room. However, too much reverberation would reduce clarity and speech intelligibility.

This research describes the study of the acoustical conditions of different classrooms at McNeese State University. The study includes an acoustical survey of unoccupied classrooms. Sound pressure levels (both A- and C-weighted) and reverberation times were measured. In this research, we focus on background noise due to the HVAC (heating, ventilation and air conditioning) systems. The results are compared with the ANSI standards to check if the acoustical conditions are adequate and if any improvement is necessary.

## 2. Literature review

Many experiments and research work have been carried out on classroom acoustics, optimum reverberation time and background noises. Houtgast [1] determined, from the classroom measurements, that the signal to noise ratio of more than 15 dB is desirable for good communication in the classroom. Research done by Bradley [2] shows that to obtain a 100% speech intelligibility, reverberation time should not exceed 0.7 s. Hodgson [3, 4] conducted acoustical measurements in 30 randomly chosen unoccupied classroom in the University of British Columbia. His results showed that the UBC classroom stock is so far from optimum acoustical quality when unoccupied. He found that many classrooms have excessive reverberation and results in low speech levels, especially at the back of the room and noisy ventilation. He found that A-weighted noise level for unoccupied classroom with standard activity is averaged at 37 dB. Knecht et. al. [5] compared their results with the limitations recommended in the American National Standard Institute standard for the acoustical characteristic of classrooms in USA (ANSI S12.60-2002). Their results indicated that most classrooms were not in compliance with ANSI noise and reverberation standards.

The American national standard ANSI S12.60 “Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools” regulates that the one-hour average A- and C-weighted background noise levels should be no more than 35 dBA and 55 dBC, respectively. Both the A- and C-weighted background noise levels must be satisfied. Reverberation time should be no more than 0.6 s for classrooms with volume less than 10,000 ft$^3$, and no more than 0.7 s for classrooms with volume more between 10,000 ft$^3$ and 20,000 ft$^3$.

## 3. Experimental setup

### 3.1 Sensors and software

The measurement system consists of the following devices.

- A PCB 378C20 omnidirectional microphone. The sensitivity is 50 mV/Pa.
- A PCB microphone calibrator CAL200.
- A USB-based data acquisition device, NI 9234. This device has four 24-bit synchronous channels and each channel can provide ICP constant current power supply for the sensor.
- Software developed using LabVIEW. The software’s user interface is shown in Figure 1. One can adjust the sensor’s information, frequency range, frequency weighting. The interface displays the real-time waveform, sound pressure level, and 1/3 spectrum. User can calibrate the microphone, record data to hard drive, and present saved data files.
- Miscellaneous equipment also includes a tripod for the microphone and a laser distance device to measure the dimensions of a room.

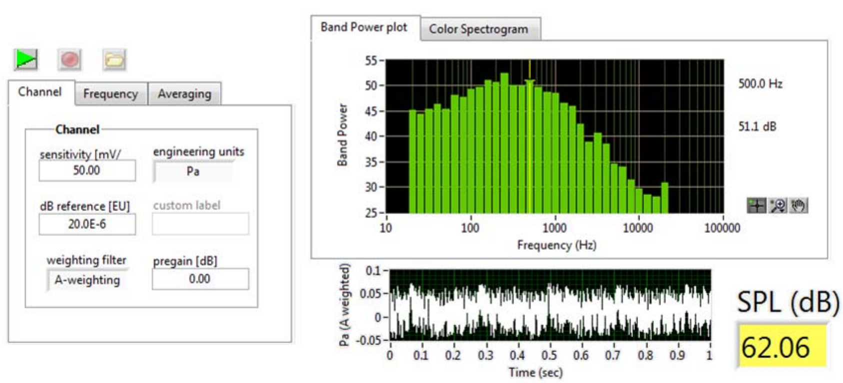


Figure 1. User interface of data acquisition software.

### 3.2 Reverberation time

Measurements were conducted when the classroom is unoccupied and doors are closed. Clapping technique was used to measure the reverberation time. In the LabVIEW software recording time of 30 seconds was set for small classrooms and 45-50 seconds for large classrooms. Depending upon the classroom size, five to eight claps were done at different locations of the classroom at an interval of minimum five seconds between claps.

Acquired data were opened and analyzed in the LabVIEW software. Figure 2 illustrates a typical reverberation measurement, where figure (a) shows the raw time waveform and (b) is the calculated sound pressure level. Two cursors were moved to choose a range of straight-line decay. For each clap the first 5 dB decay were ignored. Then a straight-line curve fitting was performed between the two cursors. In Figure 2 (b) the red line is the best straight line by least square algorithm. The reverberation time is the calculated using

$$T_{60} = \frac{60}{m}, \tag{1}$$

where *m* is the slope of the straight line. The same procedure for all the claps.

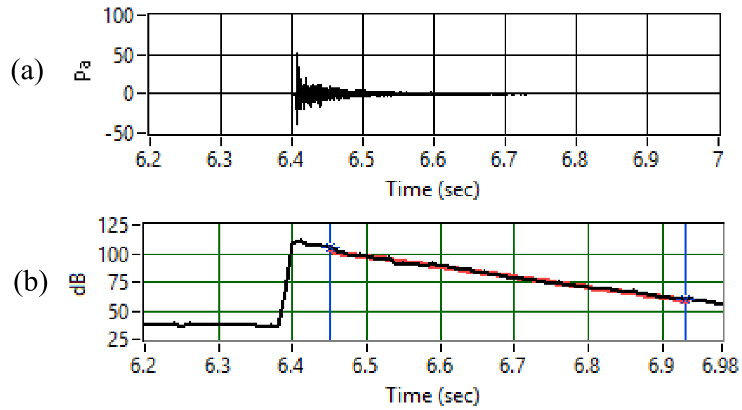


Figure 2. Reverberation time measurement.
(a) Raw time waveform; (b) Sound pressure level and straight line fitting.

### 3.3 Background noise

The experimental setup for background noise was almost the same as that for reverberation time. The HVAC system was the main background noise source considered in this experiment. Measurements were conducted when the classroom is unoccupied and doors are closed at all times to avoid any unwanted external noise. Recording time of 30 minutes was set in the software. Based on the ANSI standard S12.60-2010, both the A- and C-weighted sound pressure levels are required to evaluate the classroom background noise. Therefore, the LabVIEW software records non-weighted noise data to the hard drive, and applies the A- and C-weightings after the 30-minute data acquisition is finished. Then both the A- and C-weighted sound pressure levels are presented. The same procedure was used for all the classrooms.

## 4. Results and Discussions

Table 1 lists the test results of reverberation time and background noise of nine different classrooms in BBC (Burton Business Centre). Except Room 119 whose background noise level is barely acceptable, all other rooms are quite noisy even when the AC is off. Regarding the reverberation time, rooms 120, 201, 301, 304 and 305 require more sound absorption.

Table 1. Test results of Burton Business Centre

| Room | Volume (ft$^3$) | RT(sec) | Condition | dBA | dBC |
|---|---|---|---|---|---|
| 119 | 7,956 | 0.622 | AC on | 36.2 | 56.8 |
| | | | AC off | - | - |
| 120 | 8,872 | 1.077 | AC on | 52.5 | 63.6 |
| | | | AC off | 41.5 | 61.1 |
| 121 | 8,505 | 0.695 | AC on | 47.7 | 60.2 |
| | | | AC off | 38.1 | 56.8 |
| 122 | 6,905 | 0.695 | AC on | 56.1 | 68.3 |
| | | | AC off | 53.9 | 65.9 |
| 153 | 13,910 | 0.651 | AC on | 52.1 | 62.8 |
| | | | AC off | 39.6 | 56.1 |
| 201 | 9,450 | 1.002 | AC on | 55.8 | 63.1 |
| | | | AC off | 41.9 | 59.9 |
| 301 | 9,450 | 1.002 | AC on | 55.8 | 63.1 |
| | | | AC off | 41.9 | 59.9 |
| 304 | 9,450 | 1.002 | AC on | 55.8 | 63.1 |
| | | | AC off | 41.9 | 59.9 |
| 305 | 8,872 | 1.077 | AC on | 52.5 | 63.6 |
| | | | AC off | 41.5 | 61.1 |

Table 2 lists the test results of reverberation time and background noise of 12 different classrooms in Drew Hall. Seven classrooms have satisfactory background noise when AC is off: 110, 125, 126, 219, 229, 320, and 321. However, when AC is on, all the rooms are quite noisy. Regarding the reverberation time, most of the classrooms are fine except room 320 requires more sound absorption.

Table 2. Test results of Drew Hall

| Room | Volume (ft$^3$) | RT(sec) | Condition | dBA | dBC |
|---|---|---|---|---|---|
| 107 | 10,323 | 0.85 | AC on | 55.1 | 66.6 |
| | | | AC off | - | - |
| 110 | 6,426 | 0.728 | AC on | 54.0 | 64.0 |
| | | | AC off | 33.6 | 53.9 |
| 125 | 6,417 | 0.78 | AC on | 51.7 | 61.7 |
| | | | AC off | 34.4 | 55.8 |
| 126 | 6,417 | 0.747 | AC on | 51.2 | 68.2 |
| | | | AC off | 35.3 | 53.0 |
| 219 | 7,533 | 0.696 | AC on | 55.2 | 67.9 |
| | | | AC off | 32.8 | 51.8 |
| 229 | 8,190 | 0.681 | AC on | 48.4 | 57.0 |
| | | | AC off | 36.2 | 51.9 |
| 303 | 9,870 | 0.728 | AC on | 49.9 | 63.7 |
| | | | AC off | 37.2 | 61.8 |
| 304 | 9,450 | 0.540 | AC on | 55.8 | 63.1 |
| | | | AC off | 41.9 | 55.9 |
| 305 | 8,872 | 0.76 | AC on | 52.5 | 63.6 |
| | | | AC off | 41.5 | 61.1 |
| 320 | 7,264 | 0.952 | AC on | 48.9 | 61.2 |
| | | | AC off | 32.7 | 49.1 |
| 321 | 7,481 | 0.74 | AC on | 49.9 | 60.8 |
| | | | AC off | 33.5 | 55.4 |
| 328 | 7,238 | 0.74 | AC on | 57.5 | 66.7 |
| | | | AC off | 42.6 | 61.5 |

Table 3 lists the test results of reverberation time and background noise of 12 different classrooms in Farrar Hall. When AC is on, all the rooms are quite noisy except room 112. Regarding the reverberation time, most of the classrooms are fine except room 321 requires more sound absorption.

Table 3. Test results of Farrar Hall

| Room | Volume (ft3) | RT(sec) | Condition | dBA | dBC |
|---|---|---|---|---|---|
| 112 | 4,931 | 0.587 | AC on | 35.9 | 56.2 |
| | | | AC off | - | - |
| 132 | 5,576 | 0.623 | AC on | 48.7 | 66.8 |
| | | | AC off | - | - |
| 137 | 8,516 | 0.693 | AC on | 48.8 | 63.3 |
| | | | AC off | - | - |
| 141 | 4,817 | 0.626 | AC on | 45.9 | 60.8 |
| | | | AC off | - | - |
| 232 | 5,670 | 0.496 | AC on | 34.8 | 60.2 |
| | | | AC off | - | - |
| 216 | 8,100 | 0.65 | AC on | 48.1 | 69.4 |
| | | | AC off | - | - |
| 221 | 5,130 | 0.807 | AC on | 40.8 | 67.9 |
| | | | AC off | - | - |
| 239 | 6,210 | 0.611 | AC on | 55.8 | 63.1 |
| | | | AC off | 41.9 | 55.9 |
| 306 | 6,750 | 0.78 | AC on | 52.5 | 63.6 |
| | | | AC off | 41.5 | 61.1 |
| 321 | 8,100 | 1.085 | AC on | 48.9 | 61.2 |
| | | | AC off | 32.7 | 49.1 |
| 322 | 7,830 | 0.698 | AC on | 49.9 | 60.8 |
| | | | AC off | 33.5 | 55.4 |
| 332 | 7,290 | 0.769 | AC on | 57.5 | 66.7 |
| | | | AC off | 42.6 | 61.5 |

Table 4 lists the test results of reverberation time and background noise of Frasch Hall. As half of the building was closed for reconstruction, we only measured four classrooms. The AC is always on and the background noise levels are quite higher than the standard for every classroom. Regarding the reverberation time, most of the classrooms are fine except room 130.

Table 4. Test results of Frasch hall

| Room | Volume (ft3) | RT(sec) | Condition | dBA | dBC |
|---|---|---|---|---|---|
| 130 | 24,596 | 0.986 | AC on | 44.8 | 62.3 |
| 136 | 6,928 | 0.657 | AC on | 51.9 | 72.9 |
| 138 | 4,778 | 0.577 | AC on | 44.8 | 64.1 |
| 337 | 6,639 | 0.648 | AC on | 45.0 | 57.7 |

Table 5 lists the test results of reverberation time and background noise of four classrooms in Hardtner Hall. The AC is always on for every classroom, but the background noise levels are satisfactory except room 304. Regarding the reverberation time, most of the classrooms are fine except room 304 requires more sound absorption.

Table 6 lists the test results of reverberation time and background noise of 13 classrooms in Kirkman Hall. All the classrooms have unsatisfactory background noise levels. Regarding the reverberation time, most of the classrooms are fine except rooms 108, 109, and 115 require more sound absorption.

Table 5. Test results of Hardtner Hall

| Room | Volume (ft$^3$) | RT(sec) | Condition | dBA | dBC |
|---|---|---|---|---|---|
| 103 | 15,800 | 0.646 | AC on | 37.6 | 55.8 |
| 104 | 15,800 | 0.596 | AC on | 36.4 | 55.7 |
| 106 | 6682 | 0.702 | AC on | 36.7 | 52.7 |
| 304 | 8463 | 0.969 | AC on | 42.9 | 64.3 |

Table 6. Test results of Kirkman Hall

| Room | Volume (ft$^3$) | RT(sec) | Condition | dBA | dBC |
|---|---|---|---|---|---|
| 107 | 7,841 | 0.77 | AC on | 37.8 | 59.6 |
| | | | AC off | - | - |
| 108 | 7,349 | 0.95 | AC on | 36.7 | 59.8 |
| | | | AC off | - | - |
| 109 | 7,349 | 0.95 | AC on | 36.7 | 59.8 |
| | | | AC off | - | - |
| 111 | 7,168 | 0.69 | AC on | - | - |
| | | | AC off | 38.5 | 62.1 |
| 115 | 7,349 | 0.95 | AC on | 36.7 | 59.8 |
| | | | AC off | - | - |
| 123 | 6,518 | 0.7 | AC on | 52.2 | 68.6 |
| | | | AC off | 44.1 | 66.0 |
| 124 | 6,518 | 0.77 | AC on | 52.2 | 68.6 |
| | | | AC off | 44.1 | 66.0 |
| 126 | 6,128 | 0.73 | AC on | 41.4 | 62.4 |
| | | | AC off | - | - |
| 140 | 5,343 | 0.58 | AC on | 43.4 | 63.1 |
| | | | AC off | - | - |
| 200 | 7,013 | 0.567 | AC on | 42.6 | 67.3 |
| | | | AC off | - | - |
| 202 | 7,347 | 0.792 | AC on | 45.7 | 65.0 |
| | | | AC off | - | - |
| 203 | 6,473 | 0.684 | AC on | 44.8 | 69 |
| | | | AC off | - | - |
| 204 | 8190 | 0.593 | AC on | 41.6 | 65.0 |
| | | | AC off | - | - |

Table 7. Test results of Kauffman Hall

| Room | Volume (ft$^3$) | RT(sec) | Condition | dBA | dBC |
|---|---|---|---|---|---|
| 200 | 5,116 | 0.636 | AC on | 38.3 | 54.9 |
| 201 | 8,224 | 0.58 | AC on | 47.6 | 62.2 |
| 202 | 8,403 | 0.616 | AC on | 46.9 | 61.3 |
| 203 | 5,016 | 0.628 | AC on | 48.7 | 63.4 |
| 205 | 5,671 | 0.789 | AC on | 36.4 | 54.8 |
| 207 | 5,787 | 0.632 | AC on | 49.0 | 65.0 |
| 208 | 5,328 | 0.618 | AC on | 49.3 | 65.1 |
| 214 | 9,769 | 0.969 | AC on | 44.6 | 64.4 |
| 215 | 9,770 | 0.943 | AC on | 45.2 | 68.4 |
| 216 | 6,697 | 0.859 | AC on | 47.4 | 63.0 |
| 217 | 6,733 | 0.961 | AC on | 39.9 | 60.6 |
| 219 | 6,758 | 0.879 | AC on | 48.8 | 65.1 |
| 220 | 6,690 | 0.794 | AC on | 50.1 | 65.3 |
| 322 | 9,769 | 0.969 | AC on | 44.6 | 64.4 |
| 327 | 6,714 | 0.94 | AC on | 48.8 | 66.3 |

Table 7 lists the test results of reverberation time and background noise of 15 classrooms in Kauffman Hall. The AC is always on for every classroom. Although reconstruction was done two years ago, only two classrooms have satisfactory background noise: 200 and 205. In addition, many rooms also suffer from long reverberation time: 205, 214, 215, 216, 217, 219, 220, 322, 327.

Table 8 lists the test results of reverberation time and background noise of 11 classrooms in Gayle Hall. It can be seen that all these rooms suffer from bad acoustics.

Table 8. Test results of Gayle Hall

| Room | Volume ($ft^3$) | RT(Sec) | Condition | dBA | aBC |
|---|---|---|---|---|---|
| 104B | 34,302 | 1.174 | AC on | 41.8 | 60.4 |
| | | | AC off | - | - |
| 104C | 16,602 | 1.073 | AC on | 36.3 | 58.9 |
| | | | AC off | - | - |
| 203 | 6,518 | 0.856 | AC on | 47.5 | 55.7 |
| | | | AC off | 45.0 | 52.2 |
| 206 | 9,067 | 0.938 | AC on | 48.1 | 60.0 |
| | | | AC off | 46.3 | 53.3 |
| 212 | 14,577 | 0.673 | AC on | 43.3 | 55.2 |
| | | | AC off | - | - |
| 301 | 8,941 | 0.968 | AC on | 45.4 | 56.5 |
| | | | AC off | 38.9 | 52.2 |
| 302 | 11,710 | 0.908 | AC on | 48.8 | 57.0 |
| | | | AC off | 47.1 | 53.2 |
| 303 | 6,255 | 0.924 | AC on | 47.9 | 58.0 |
| | | | AC off | 40.7 | 54.6 |
| 304 | 5,961 | 0.822 | AC on | 45.8 | 57.8 |
| | | | AC off | 40.0 | 52.1 |
| 305 | 6,261 | 0.885 | AC on | 46.9 | 57.8 |
| | | | AC off | 37.9 | 52.3 |
| 308 | 11,191 | 0.52 | AC on | 45.5 | 55.5 |
| | | | AC off | 40.4 | 52.9 |

Based on the data shown above, statistical analysis results can be summarized as follows.

- There are 70 classrooms that are less than 10,000 $ft^3$. Reverberation times are in a range from 0.5 s to 1.1 s with average 0.77 s and standard deviation 0.15 s. Only 9 classrooms (12.9 %) satisfy the ANSI S12.60 requirement ($RT \leq 0.6$ s).
- There are 9 classrooms whose volumes are between 10,000 $ft^3$ and 20,000 $ft^3$. Reverberation times are in a range from 0.52 s to 1.07 s with average 0.81 s and standard deviation 0.22 s. Five classrooms (55.6 %) satisfy the ANSI S12.60 requirement ($RT \leq 0.7$ s).
- A two-sample *t*-test indicates that the reverberation times of smaller classrooms are not significantly less than those of larger classrooms (*p* value is 0.326).
- For classrooms with AC on (79 samples), the A-weighted background noise levels are in a range from 34.8 dBA to 57.5 dBA with average 50.2 dBA. The C-weighted background noise levels are in a range from 52.7 dBC to 72.9 dBC with average 64.2 dBC.
- For classrooms with AC off (35 samples), the A-weighted background noise levels are in a range from 32.7 dBA to 53.9 dBA with average 42.9 dBA. The C-weighted background noise levels are in a range from 49.1 dBC to 66 dBC with average 59.5 dBC.
- Two-sample *t*-tests indicate that the background noise levels with AC off is significantly less than those with AC on. Figure 3 and Figure 4 compare the histograms of background noise levels with and without AC.

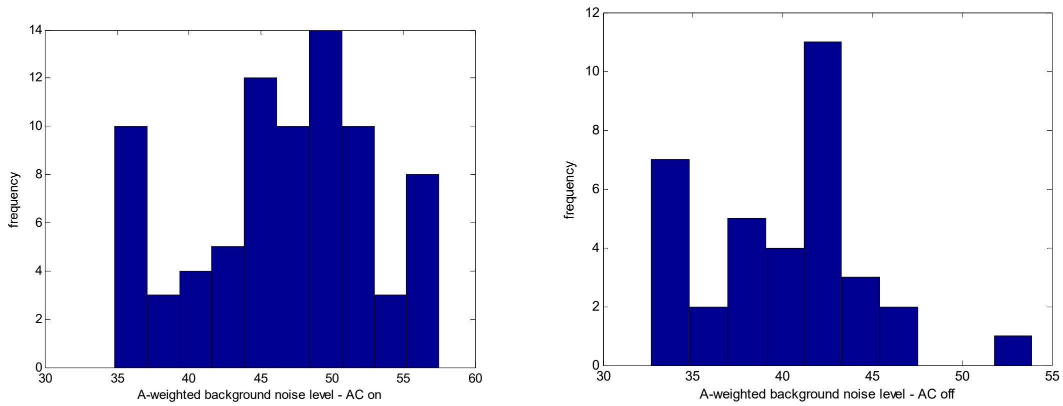


Figure 3. A-weighted background noise of classrooms

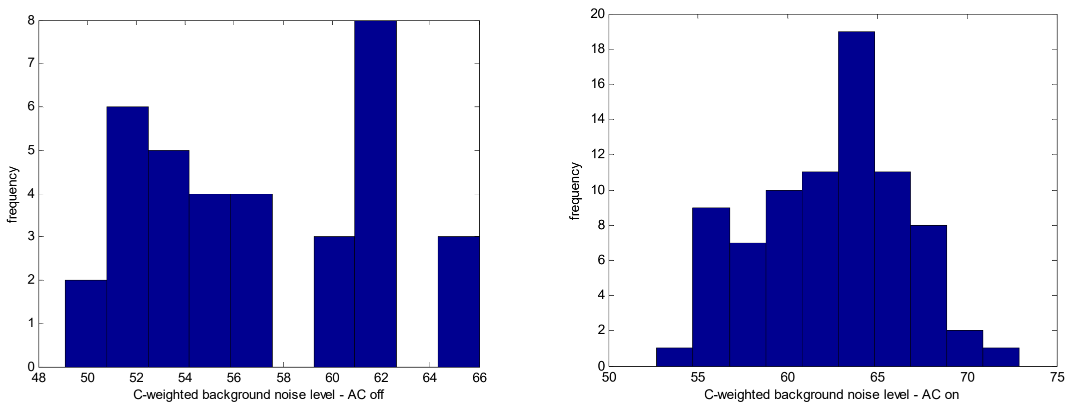


Figure 4. C-weighted background noise of classrooms

## 5. Conclusions

A detailed survey of the acoustical condition of classroom was carried out for 80 classrooms at McNeese State University. The results of the classroom acoustical survey show that the overall acoustical quality of unoccupied classroom is far from optimum.

Many classrooms have excessive reverberation time. This problem can be solved by increasing the sound absorption areas in these classrooms. The most effective way is to upgrade acoustical ceiling tiles with high NRC (e.g. 0.9 or 0.95). The amount of sound absorption will be calculated in the next phase of the project.

Many classrooms have high background noise level due to the ventilation system. This is a more serious problem. First, there are various HVAC noise sources: fans, duct radiation, flow noise, etc. Second, the ductwork is either above suspended ceilings or in shafts. So they are more difficult to access. In addition, the resolutions to HVAC noise are more expensive. In the next phase of the project, the noise mitigation methods will be recommended.

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