# Hand Dryer's Noise Level and its Effect on Human Hearing

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**Abstract**

Hand dryers are objects in our daily life. However, the noise levels of hand dryers are generally paid little attention since few studies are conducted to investigate this issue (Berkowitz(2015)). Keegan(2013) indicated there are hand dryers that operate at levels far louder than their manufacturer claims, and the noise level may cause damage to children's hearing. Our research expands upon Keegan(2013) and uses an Arduino based device to investigate hand dryers' noise levels with respect to Sound Pressure Level (SPL) and frequency to see whether it can cause hearing loss for average college students.

***Keywords***— hand dryers, sound pressure level, frequency

# 1 Introduction

The noise level or ambient noise level, typically measured in dB (1dB corresponds to 20 μPa), indicates the background sound pressure level (SPL) from a specific source. The decibel (dB) is a unit used to measure the intensity of a sound or the power level of an electrical signal by comparing it with a given level on a logarithmic scale. For example, the smallest audible sound is 0 dB, and a sound 10 times more powerful is 10 dB. Typically, this noise level is measured with a particular frequency weighting filter. A-weighting filter is defined as the standard weighting filter by the International standard IEC 61672:2003 to measure the SPL. The units of this measurement are written as dB(A),which represents the A weighted dB. More details about the A-weighting filter is introduced in Section 2.4. Hearing loss can result from loud noises combined with high sound pressure levels and frequency. Noises that exceed a certain threshold could cause damage to hair cells within the human ear. The Occupational Safety and Health Administration (OSHA) has defined this exposure threshold to be 90 dBA for 8 hours working scale in 1983[1]. In 1993, the National Institute for Occupational Safety and Health (NIOSH) updated this limit to 85 dBA[2]. NIOSH has also indicated that immediate hearing loss could occur if the noise exposure level is above 120 dBA.

The presence of hand dryers reduced the need for paper towels and the consumption of wood. However, its potential noise level is often ignored (Berkowitz(2015)). Keegan (2013) indicates there are hand dryers that operate far louder than what the manufacture claim and could be potentially damaging to children's hearing.

It is possible to perform simple acoustic analyses on hand dryers' noise levels using Python scripts together with the Arduino and Adafruit library packages. Python is the computer programming language we used in this work to analyze data. Here we intend to expand upon Keegan (2013) and use Arduino based device to investigate hand dryers' noise level related to Sound Pressure Level (SPL) and frequency to see whether it can cause hearing damage to adults.

We describe the method for our measurement in Section 2. In Section 3, we introduce our measured data from the device and the interpretation of the data. In Section 4, we offer a summary together with some possible future applications of this work.

[1]Data come from Vishakha W.Rawool (2011) Hearing Conservation: In Occupational, Recreational, Educational, and Home Settings, Thieme

[2]Data come from Vishakha W.Rawool (2011) Hearing Conservation: In Occupational, Recreational, Educational, and Home Settings, Thieme

Figure 1: Taking data from hand dryers

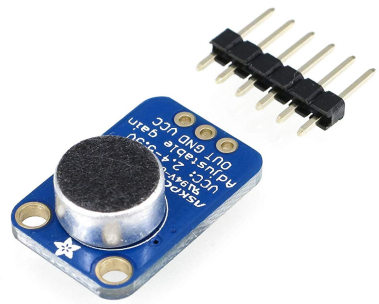
# 2 Method

## 2.1 Hardware

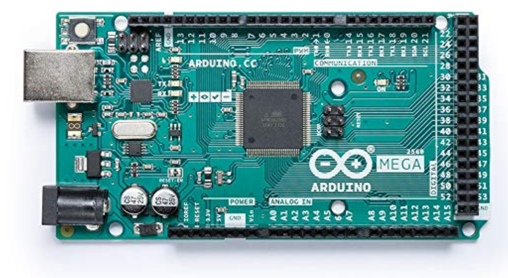
An electrical microphone is used to measure the sound pressures of hand dryers. There is a membrane in the microphone, which causes a voltage difference when the membrane vibrates. The MAX4466 is a microphone with an amplifier chip on the back of the PCB. The membrane in the microphone creates the voltage differences when it vibrates. Usually, the voltage difference across the microphone is small, so the MAX4466 amplifier chip amplifies the voltage difference and gives the voltage differences to the Arduino board. The amplifier can amplify the voltage from 25 times to 125 times. The more the voltage is amplified, the more sensitive the microphone is. This feature makes the microphone able to measure sound pressures up to 125dB and sound frequencies from 20Hz to 20kHz.

In the measurements taken in this report, the amplifiers are turned to the minimum, which is 25 times, to reduce the possibility of noises affecting the results such as static electricity noise on the circuit board.

After the voltage difference is amplified, the microphone passes the data to the Arduino MEGA 2560 at the rate 32kHz. The Arduino 2560 changes the voltage data to ADC values with respect to the reference voltage. ADC stands for analog



(a) MAX4466




(b) Arduino Mega 2560

Figure 2: MAX4466 microphone and Arduino Mega 2560. (Image adopted from Amazon.)

to digital converter, which converts voltages records to a number of records. ADC is a 10-bit reading, which means it is from 0 to 1023. The amplified voltage is changed to ADC reading by this formula:

$$V_{reading} = \frac{5 \cdot ADC_{reading}}{1023} \tag{1}$$

As the possible numbers of ADC readings are always 1024, so the higher the reference voltage is, the higher the max sound pressure. Setting higher voltage will sacrifice data precision, yet in this report, the reference voltage is still set to five volts in order to record all the data passed by the microphone without overflowing the maximum ADC output. The voltage reading in a quiet room is 1.65 volts. By using equation (1), the corresponding ADC value is 337. It is used as a reference when calculating the root mean square of each voltage measurement. The sound pressure is calculated by using the following formula:

$$SPL(dB) = 20\log_{10}\left(\frac{RMS}{ref}\right) \tag{2}$$

The reference number is calculated by using the measurements of ADC and the sound pressure value measured by the sound level meter manufactured by Extech, model 407732.The reference number for the quiet mode (sound pressure from 0 dB to 80 dB) of the sound meter is 0.034, and the noisy mode (sound pressure from 75 dB to 130 dB) is 0.0047 for the sound pressure meter.

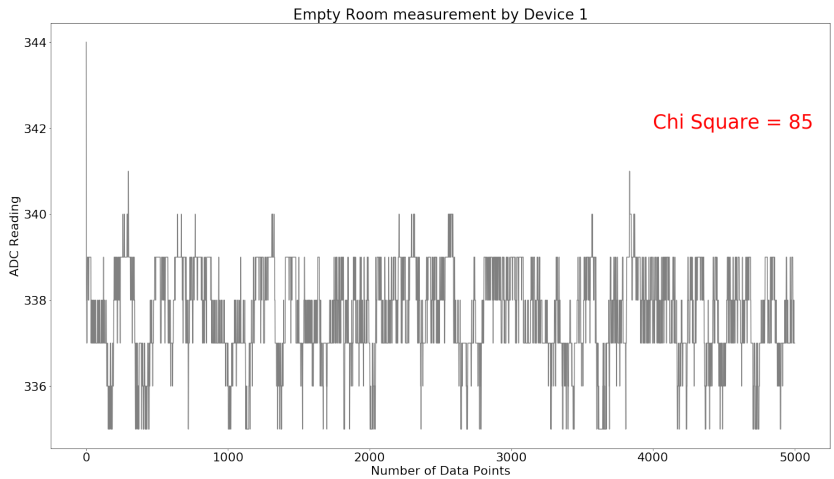

Figure 3: EXTECH INTRUMENTS Sound Level Meter Model 407732

(a) (b)

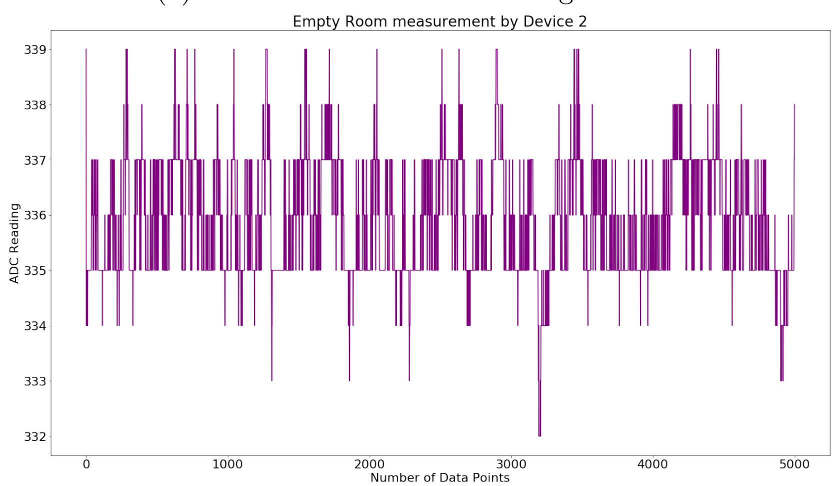
Figure 4: Final build-up of both devices.

## 2.2 Hardware Calibration

To ensure the data measurements are accurate and are not affected by hardware, there are two identical devices built. These two devices are used to measure the same period of hand dryer's noise. The results of the two devices are compared with each other to confirm there is little difference between the results taken by these two devices, so hardware differences do not alter the data measurements. The ADC measurements graph of two devices are shown in Figure 4.




(a) XLERATOR measured using device 1




(b) XLERATOR measured using device 2

Figure 5: XLERATOR ADC measurements done by using both devices

By performing a Chi-square test on the ADC data measurements, we got the result is 85, which shows the ADC recording of two devices have little differences, so the hardware differences do not alter the data measurements. Chi-square test determines the difference between two data sets. It uses the equation (3). O represents the observed data and E represents the expected data.

$$\chi^2 = \sum \frac{(O - E)^2}{E} \tag{3}$$

## 2.3 Fast Fourier Transformation (FFT)

In order to calculate the frequency of the sound recorded by the devices, a Fast Fourier transformation is applied to the ADC data. Fast Fourier transform (FFT) is an algorithm that computes the discrete Fourier transform (DFT) of a sequence. In this case, the sequence is our ADC data. Fourier analysis converts a signal from its original domain (time or space) to a representation in the frequency domain. FFT calculation in this paper is done by using Python's Numpy libraries. The fast Fourier transformation changes the time domain signal data to frequency domain signal data. It uses the identity of fast Fourier transformations, which shows the energy level each frequency corresponds to. If one frequency occurs more, the energy level corresponds to the frequency will be higher. This feature able us to generate a graph that shows the frequencies that occurs more compared with other frequencies. As the results of this transformation contain imaginary numbers, we take absolute values of the results. It turns all the results to real numbers.

## 2.4 Octave Band

In order to analyze a source on frequency more efficiently, the whole range of frequency is divided into sets of frequencies called bands. An octave band is a frequency band where the highest frequency is twice the lowest frequency. For example, an octave filter with a centre frequency of 1kHz has a lower frequency of 707Hz and an upper frequency of 1.414kHz.

| Lower Band Frequency (Hz) | Central Frequency (Hz) | Higher Band Frequency (Hz) |
|---|---|---|
| 22 | 31.5 | 44 |
| 44 | 63 | 88 |
| 88 | 125 | 177 |
| 177 | 250 | 355 |
| 355 | 500 | 710 |
| 710 | 1000 | 1420 |
| 1420 | 2000 | 2840 |
| 5680 | 8000 | 11360 |

Table 1: Corrections to be applied between frequency and dBA for A-weighting curve. Data acquired from Ref[1].

## 2.5 SPL weighting

| Central Frequency (Hz) | dBA weighting |
|---|---|
| 31.5 | -39.4 |
| 63 | -26.2 |
| 125 | -16.1 |
| 250 | -8.6 |
| 500 | -3.2 |
| 1000 | 0 |
| 2000 | 1.2 |
| 4000 | 1.1 |
| 8000 | -1.1 |

Table 2: Corrections to be applied between frequency and dBA for A-weighting curve. Data acquired from Ref[1].

To compare our data with the noise exposure limit introduced by OSHA and NIOSH, we also apply A-weighting to our FFT frequency spectrum. A-weighing is the most commonly used acoustic frequency weighing that relates to sound frequencies and human ear perception. Since human ears are more sensitive to sounds in specific frequencies, we may perceive some sound signals to be relatively louder. A-weighting filter adjusts this relation between human ear sensitivity and relative SPL. It is employed by adding a table of values to the measured sound pressure levels in dB, the resulting units are written as dBA. The gain is added or subtracted depending on the original signal's octave frequency. For example, according to Table 1, if a healthy human receives a 100 dB sound signal at 2000 Hz, a gain of 1.2 dB is added to the measured SPL when the human ears perceive the signal. The precise frequency and gain relationship are plotted in Figure 6.

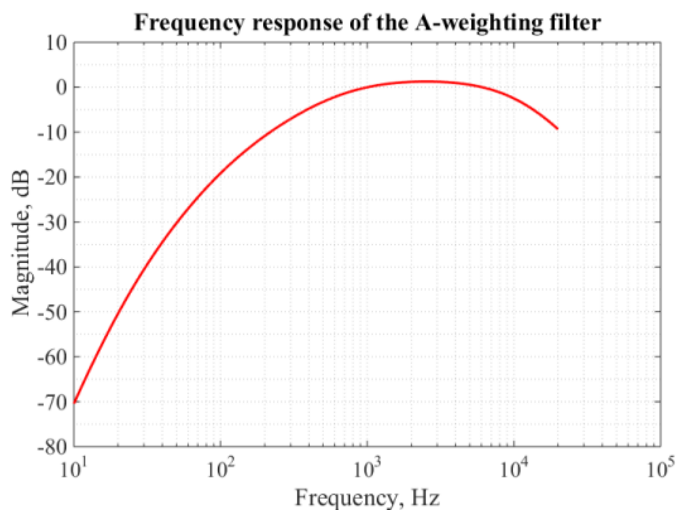



Figure 6: A-weighting curve with respect to frequency (Hz) and SPL(dB). Figure adopted from Sengpielaudio

# 3 Data and Conclusion

We have acquired ADC data from our device and computed the corresponding SPL of different hand dryers using the equation [3]. In the following, we first provide the raw ADC data acquired from MAX 4466 microphone and then show their corresponding SPL. Finally, we performed the FFT to investigate their frequency bins. We also apply the A-weighting filter to relate the calculated SPL and human ear sensitivity better.

## 3.1 Room structure

To determine whether the room structure causes differences between results, we measured hand dryers located in the bathrooms on the first and second floor in Loomis Lab. They are the same model while the bathroom on the first floor is larger than the bathroom on the second floor. The bathroom on the first floor is larger and emptier than the bathroom on the second floor. The result is shown below.

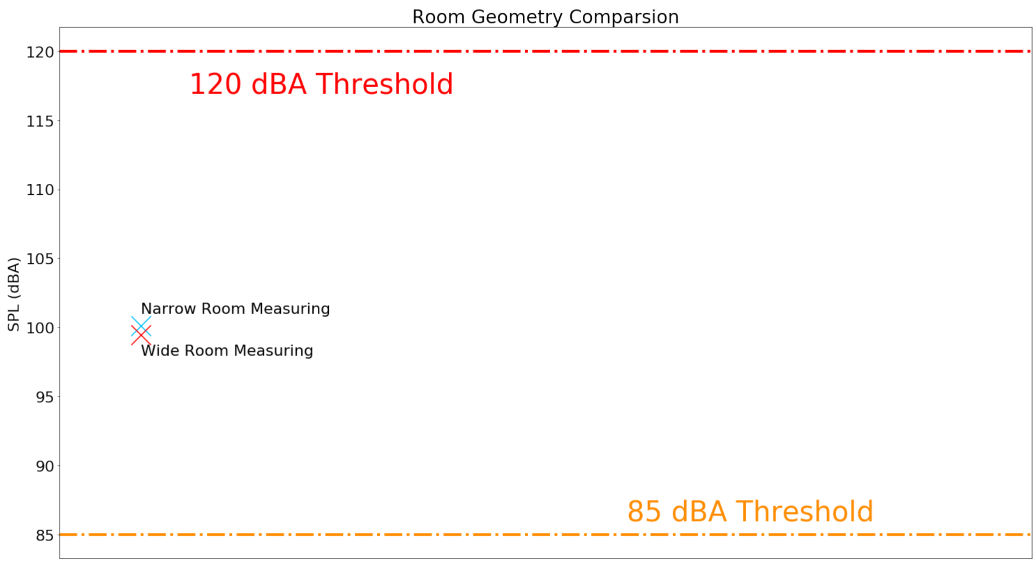
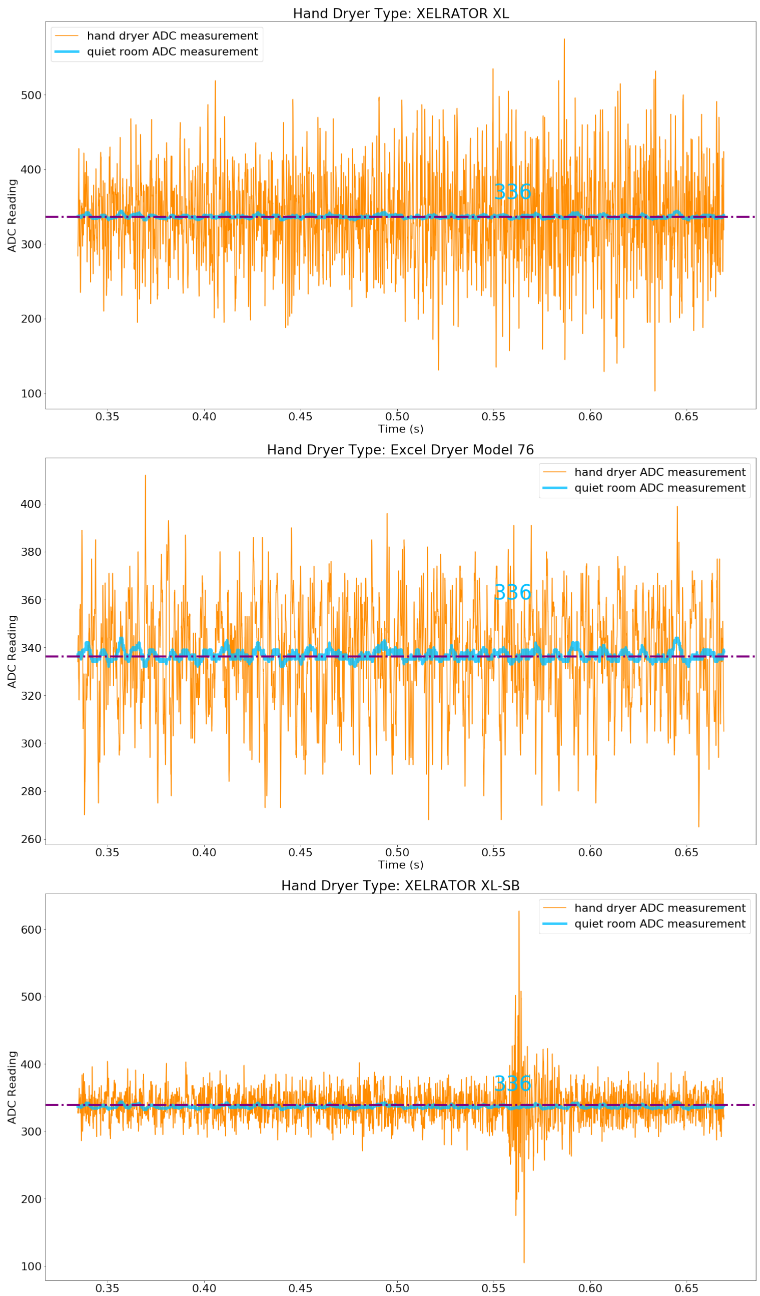


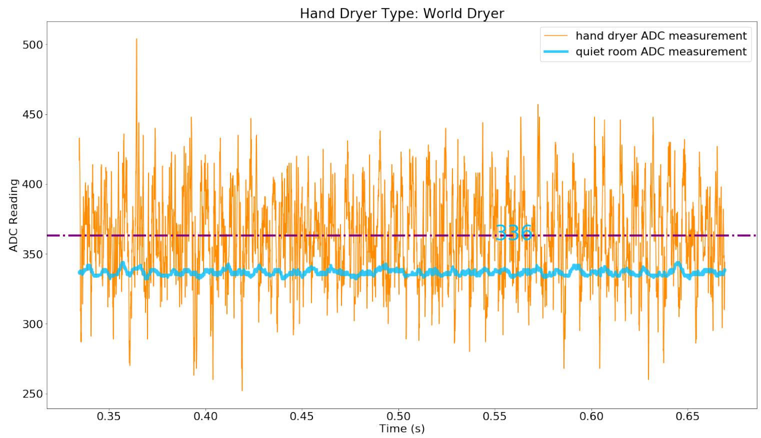

Figure 7: Comparison between different room geometry.

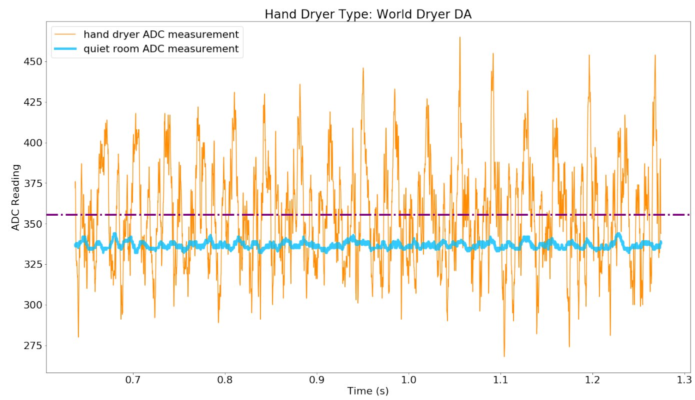
As the graph shows, the results do not have much difference. Therefore, the structure of the room does not have a significant impact on the sound pressure level of hand dryers the human ear receives in our case. However, the geometry influence of the room could be rather complicated and may also relate to the surrounding material, which is beyond the scope of this study.

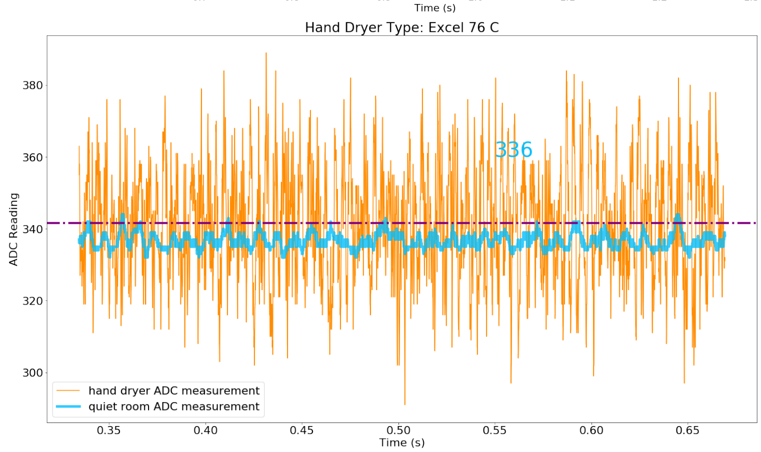
## 3.2 Raw Amplitude Data

In this section, we provide the time based raw ADC data directly measured by our Arduino based device. The overall figure is shown in Figure 7. Each panel of Figure 7 represents the measurement of different hand dryers from different manufacturers. The hand dryer's ADC measurement is also plotted with the quiet room measurement (ADC measurement for a quiet reference environment).


Hand Dryer Type: XELRATOR XL
hand dryer ADC measurement
quiet room ADC measurement
336
ADC Reading
Time (s)
Hand Dryer Type: Excel Dryer Model 76
hand dryer ADC measurement
quiet room ADC measurement
336
ADC Reading
Time (s)
Hand Dryer Type: XELRATOR XL-SB
hand dryer ADC measurement
quiet room ADC measurement
336
ADC Reading
Time (s)


Hand Dryer Type: World Dryer
hand dryer ADC measurement
quiet room ADC measurement
ADC Reading
Time (s)
336
500
450
400
350
300
250
0.35
0.40
0.45
0.50
0.55
0.60
0.65


Hand Dryer Type: World Dryer DA
hand dryer ADC measurement
quiet room ADC measurement
ADC Reading
Time (s)
450
425
400
375
350
325
300
275
0.7
0.8
0.9
1.0
1.1
1.2
1.3


Hand Dryer Type: Excel 76 C
hand dryer ADC measurement
quiet room ADC measurement
ADC Reading
Time (s)
336
380
360
340
320
300
0.35
0.40
0.45
0.50
0.55
0.60
0.65

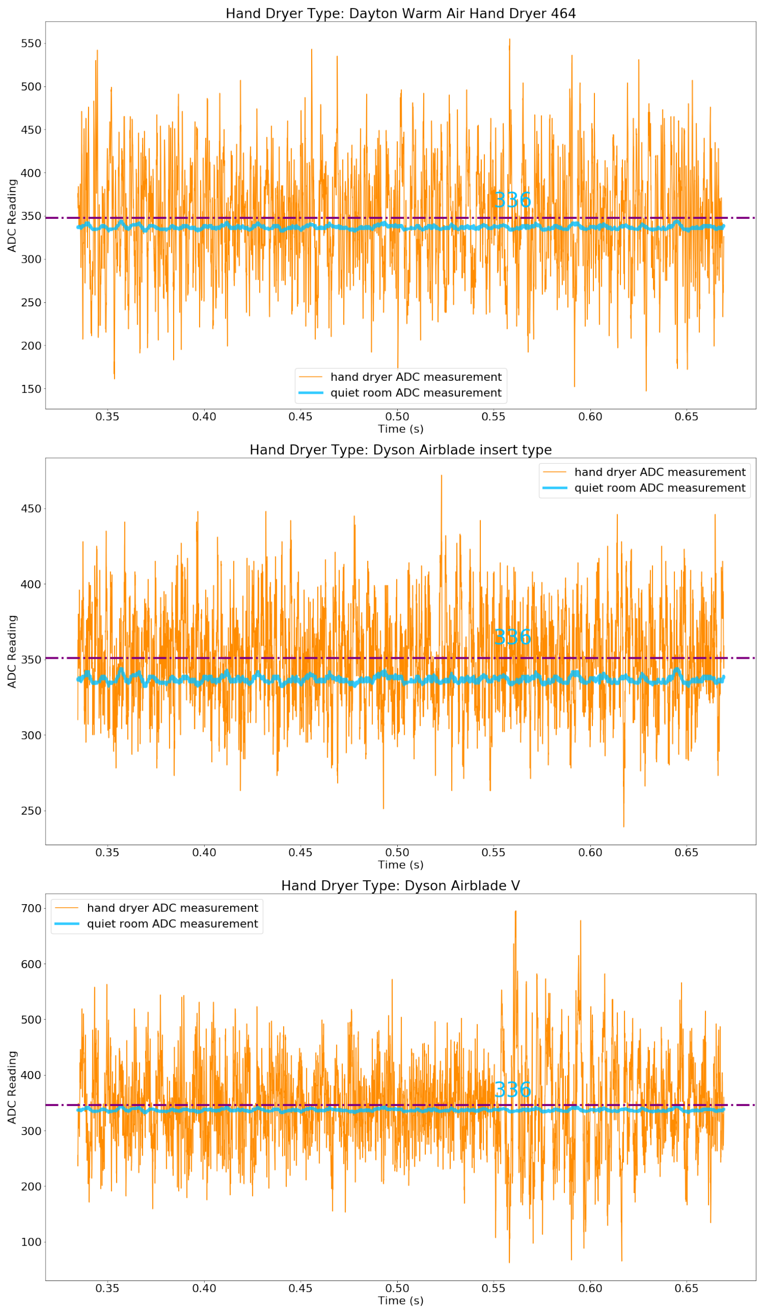
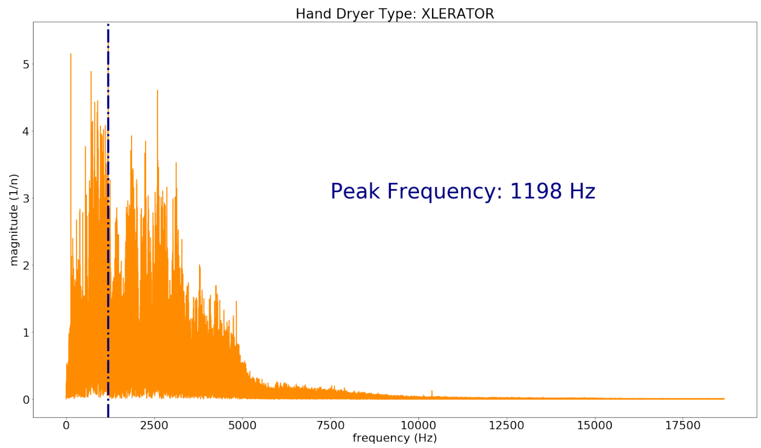
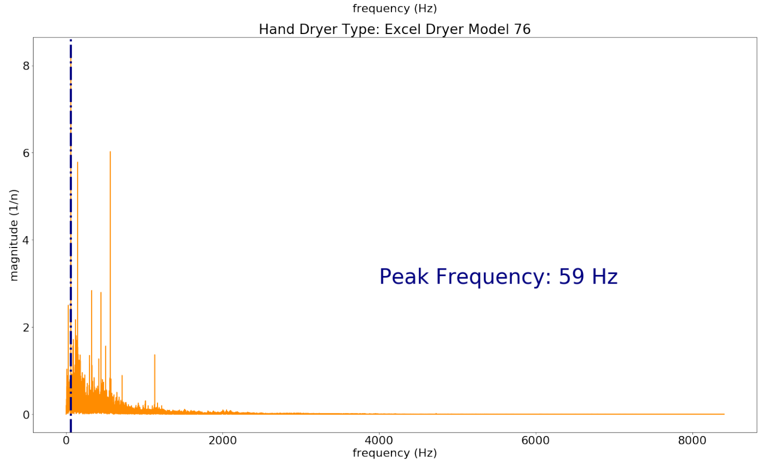


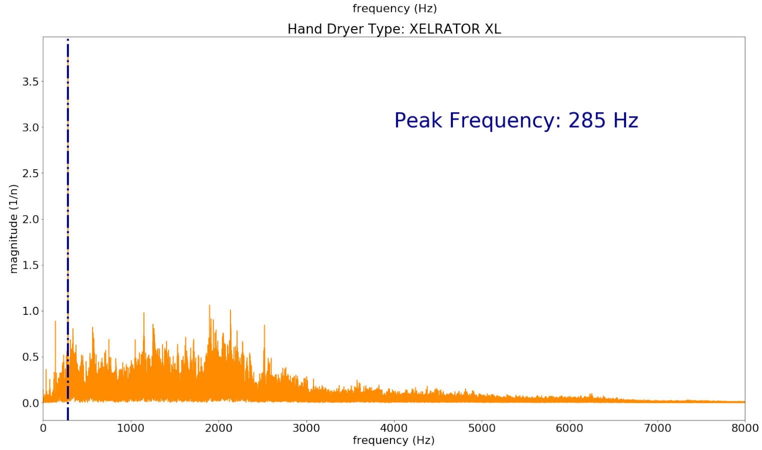

Figure 8: Each panel represents raw ADC data taken for different types of Hand dryers. The purple dashed line represents the average of the ADC signal. The blue line represents the empty room ADC output. (Around 336)

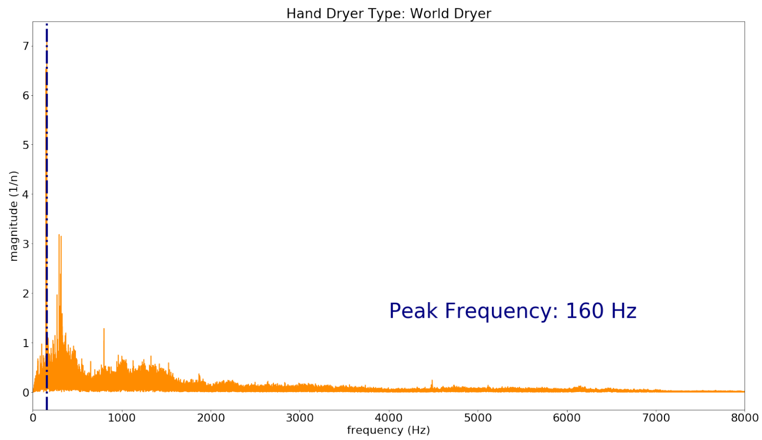
## 3.3 Frequency Spectrum

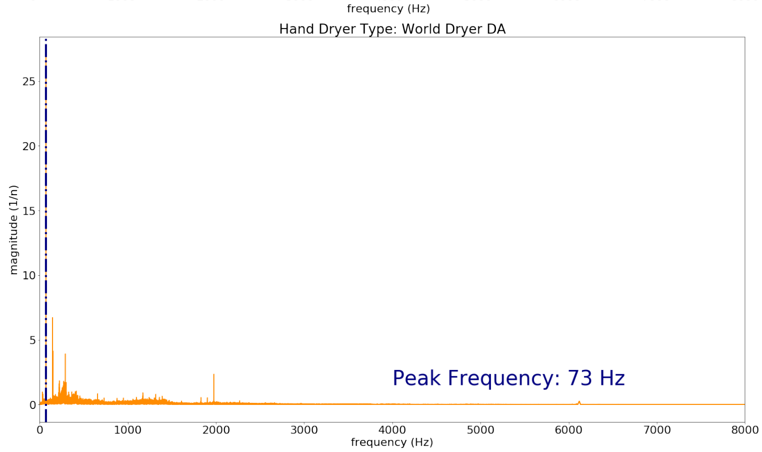
Since ADC measurements are time-based, we need to convert them to the frequency spectrum in order to apply the A-weighting frequency filter. Hence, we perform an FFT to the ADC measurement to get the frequency spectrum for hand dryers' audio data. The frequency spectrum is shown in Figure 8.

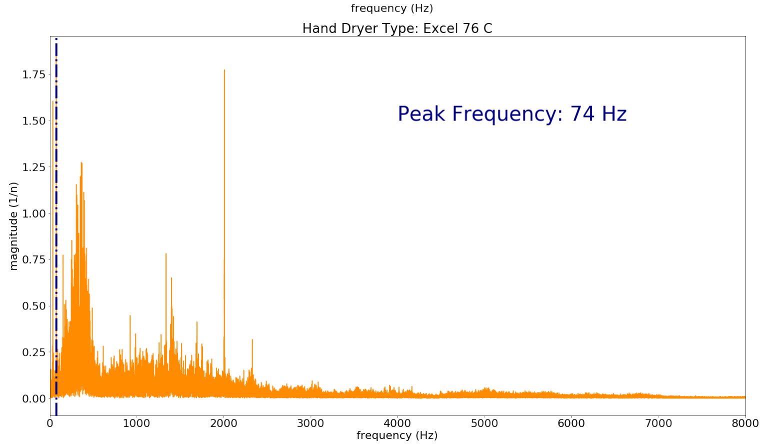

Hand Dryer Type: XLERATOR
Peak Frequency: 1198 Hz
magnitude (1/n)
frequency (Hz)
0
1
2
3
4
5
0
2500
5000
7500
10000
12500
15000
17500


Hand Dryer Type: Excel Dryer Model 76
Peak Frequency: 59 Hz
magnitude (1/n)
frequency (Hz)
0
2
4
6
8
0
2000
4000
6000
8000


Hand Dryer Type: XELRATOR XL
Peak Frequency: 285 Hz
magnitude (1/n)
frequency (Hz)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
0
1000
2000
3000
4000
5000
6000
7000
8000


Hand Dryer Type: World Dryer
magnitude (1/n)
frequency (Hz)
Peak Frequency: 160 Hz
0
1
2
3
4
5
6
7
0
1000
2000
3000
4000
5000
6000
7000
8000


Hand Dryer Type: World Dryer DA
magnitude (1/n)
frequency (Hz)
Peak Frequency: 73 Hz
0
5
10
15
20
25
0
1000
2000
3000
4000
5000
6000
7000
8000


Hand Dryer Type: Excel 76 C
magnitude (1/n)
frequency (Hz)
Peak Frequency: 74 Hz
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
0
1000
2000
3000
4000
5000
6000
7000
8000

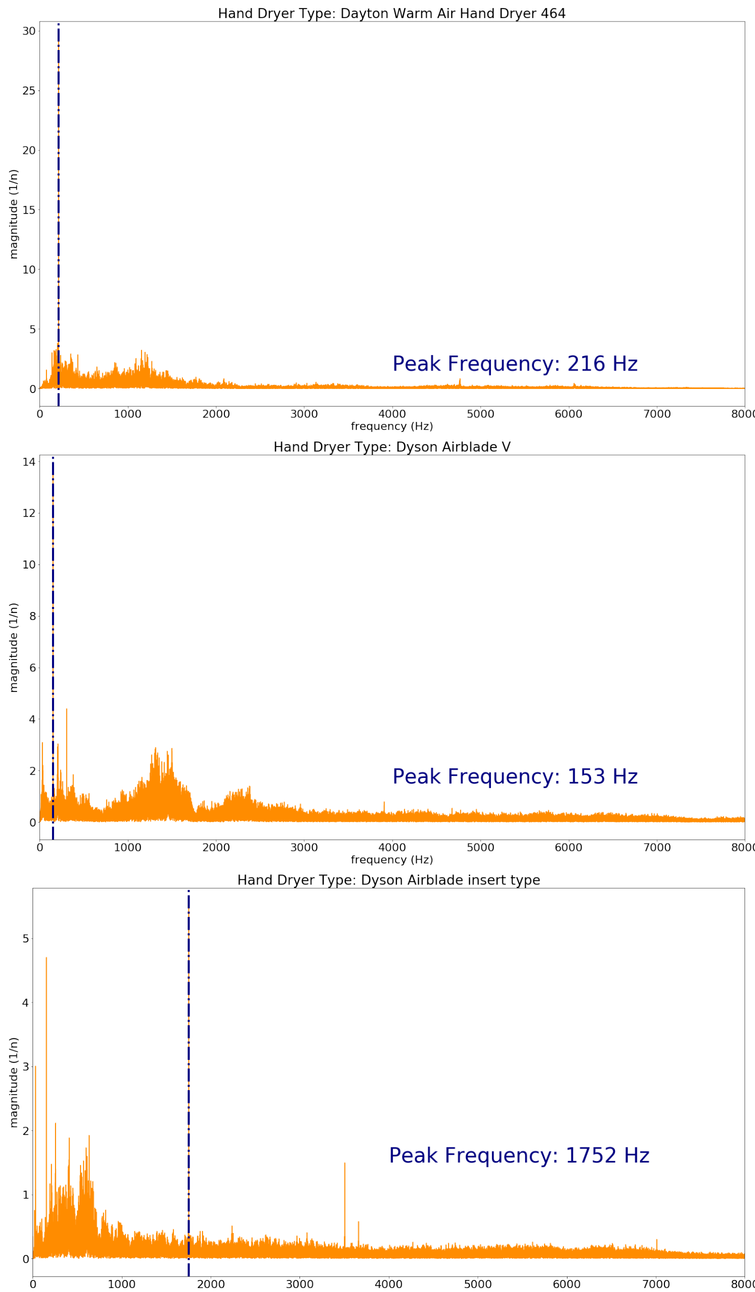
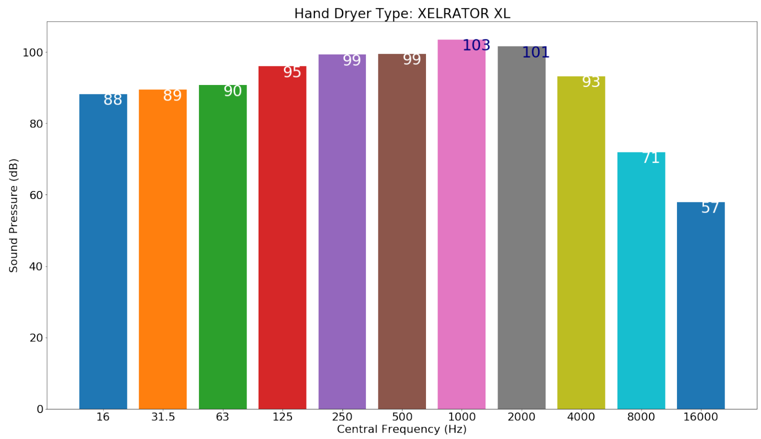
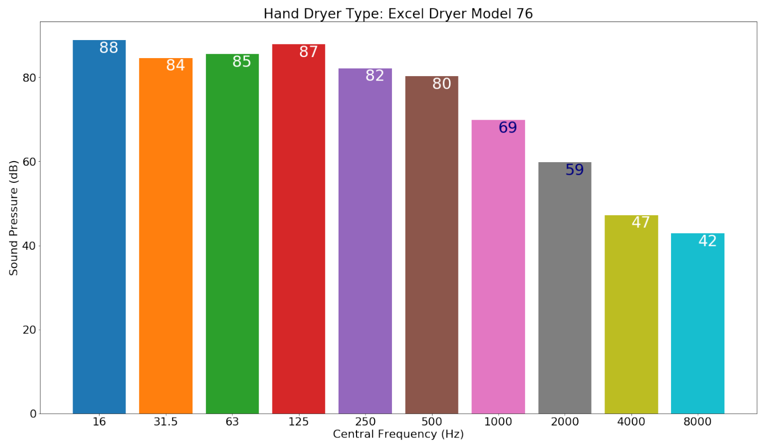


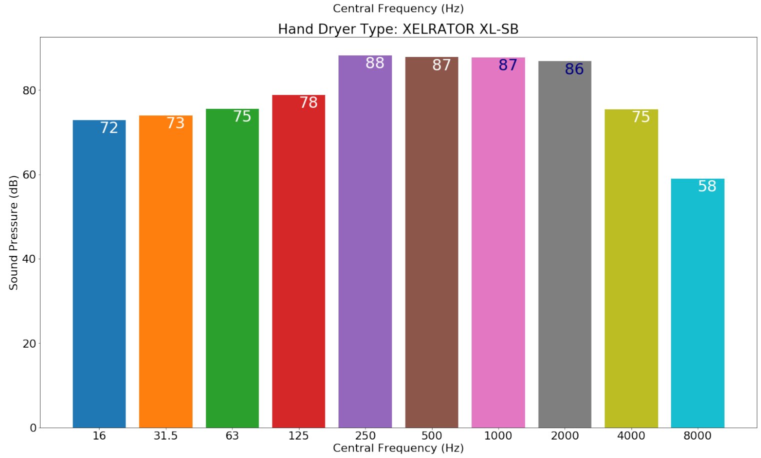

Figure 9: Each panel represents the frequency spectrum for each hand dryer's audio data. The x-axis represents corresponding frequency bins while the y-axis shows the magnitude. Magnitude is normalized by factor n (n is the total number of data points, in our case n = 268984). The vertical line indicates the peak frequency for each spectrum.

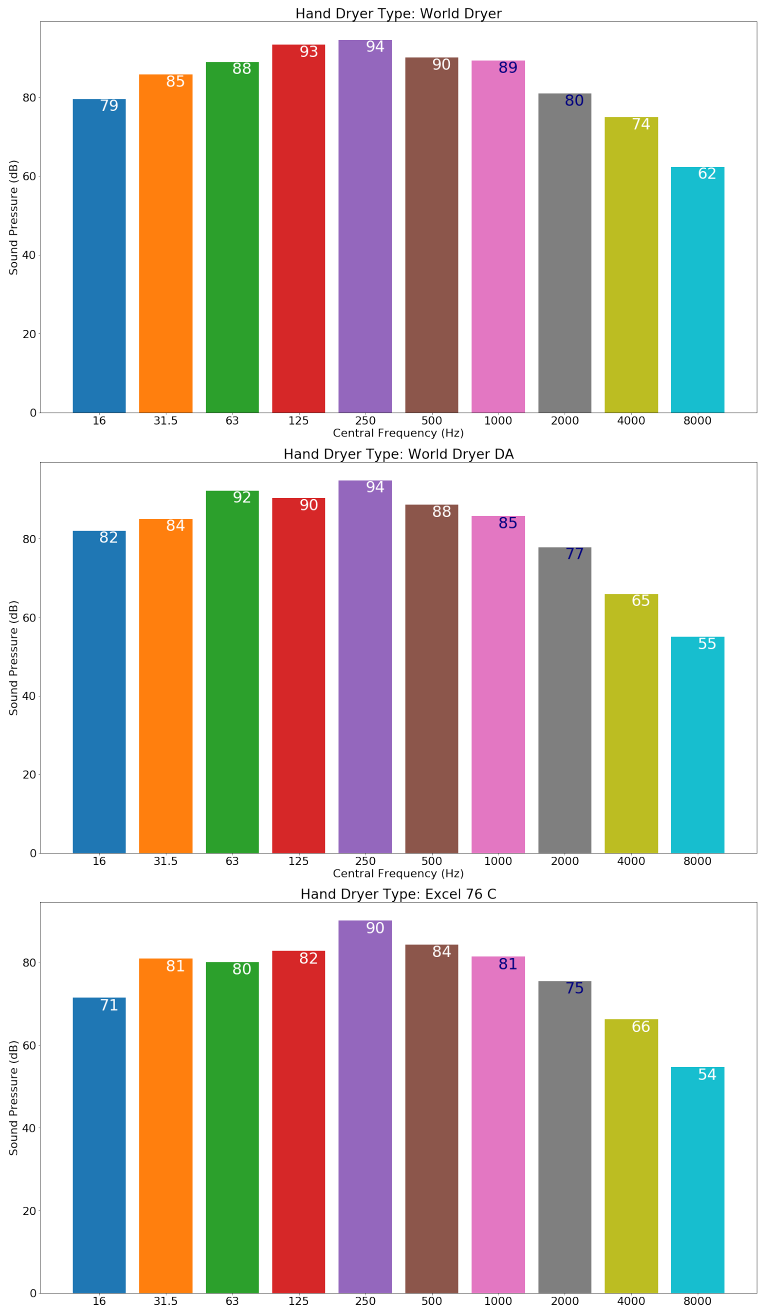
## 3.4 Octave Bands

In this subsection we provide the dB vs Octave Band frequency plot calculated from equation(1) and the above FFT data. Each bar represents the corresponding sound pressure related to Octave band central frequency. The dB vs Octave Band frequency plot is shown in Figure 10.


Hand Dryer Type: XELRATOR XL
Sound Pressure (dB)
Central Frequency (Hz)
16
31.5
63
125
250
500
1000
2000
4000
8000
16000
88
89
90
95
99
99
103
101
93
71
57


Hand Dryer Type: Excel Dryer Model 76
Sound Pressure (dB)
Central Frequency (Hz)
16
31.5
63
125
250
500
1000
2000
4000
8000
88
84
85
87
82
80
69
59
47
42


Hand Dryer Type: XELRATOR XL-SB
Sound Pressure (dB)
Central Frequency (Hz)
16
31.5
63
125
250
500
1000
2000
4000
8000
72
73
75
78
88
87
87
86
75
58



Hand Dryer Type: World Dryer
Sound Pressure (dB)
Central Frequency (Hz)
16
31.5
63
125
250
500
1000
2000
4000
8000
79
85
88
93
94
90
89
80
74
62
Hand Dryer Type: World Dryer DA
82
84
92
90
94
88
85
77
65
55
Hand Dryer Type: Excel 76 C
71
81
80
82
90
84
81
75
66
54

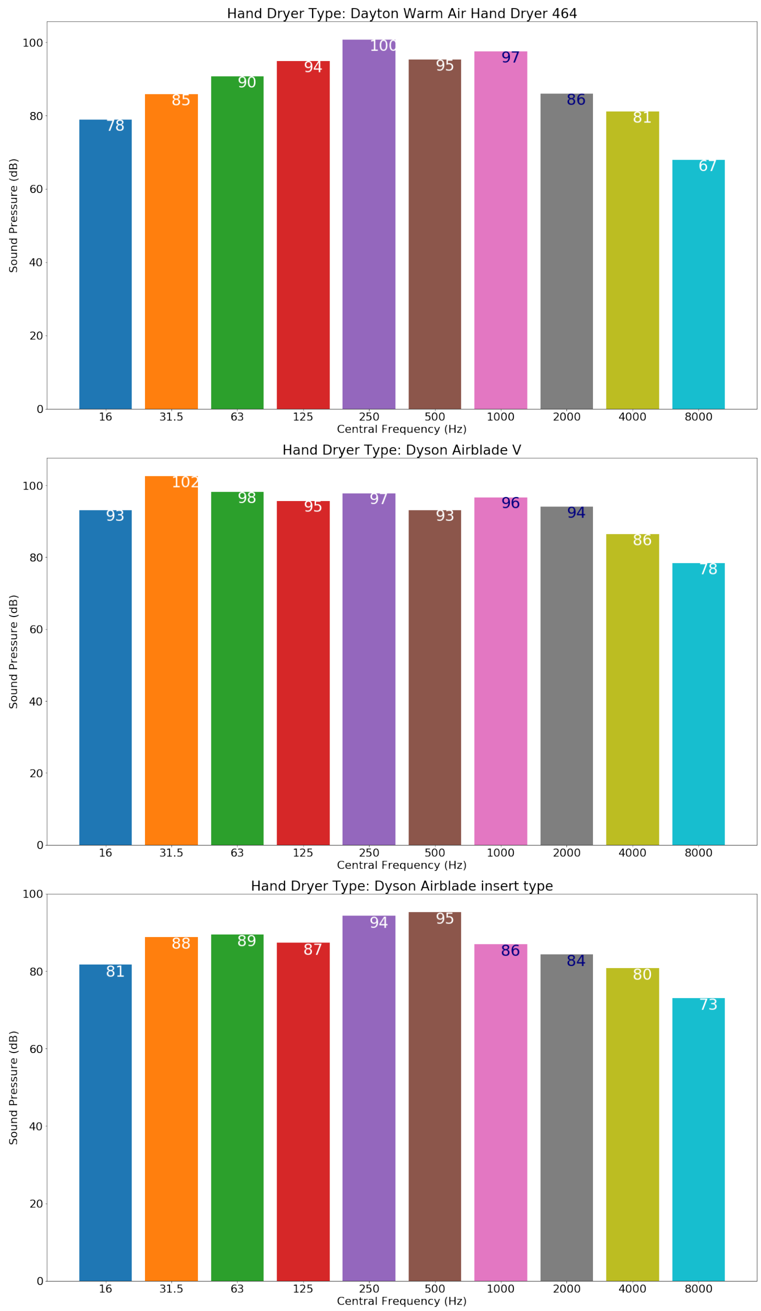



Figure 10: Each panel represents the dB vs octave band frequency for each hand dryer. The x-axis represents the central frequency bins while the y-axis shows corresponding SPL.Exact dB magnitude is annotated by each bar.

## 3.5 A-Weighted SPL

The overall weighted SPL is calculated via Table and equation (4).

$$L_{\sum} = 10\log_{10}(10^{\frac{L1}{10}} + 10^{\frac{L2}{10}} + ... + 10^{\frac{L10}{10}})dB \tag{4}$$

LΣ represents the summed sound pressure level. L1-L10 is sound pressure level calculated for each octave band

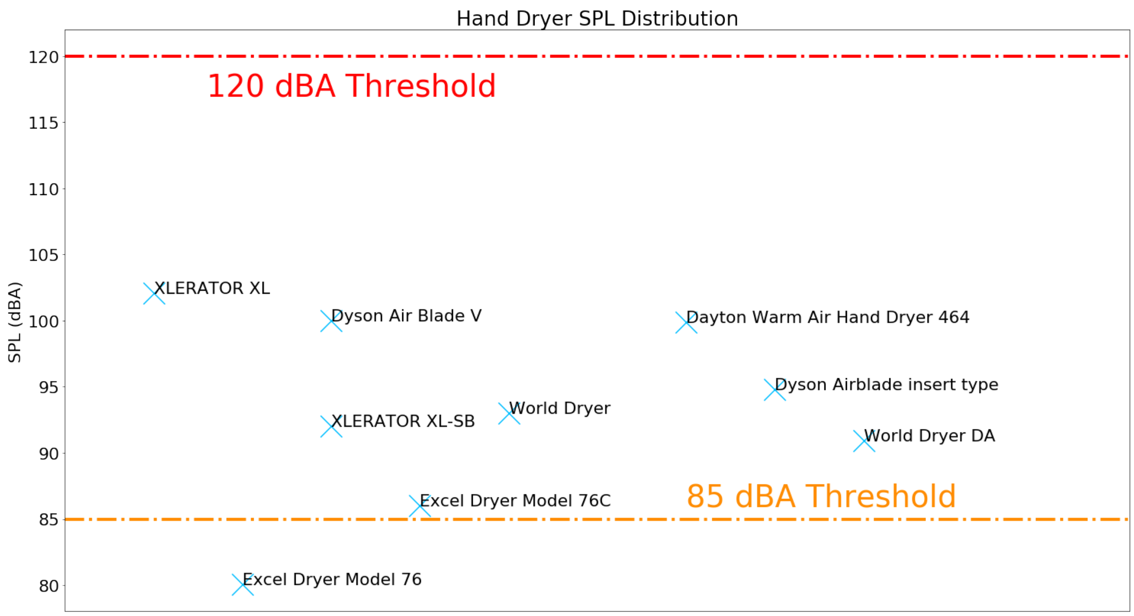



Figure 11: Each dot represents the weighted SPL measured in dBA. The red line indicates the NIOSH threshold 120 dBA, and the orange line indicates the NIOSH 85 dBA threshold for 8 hours scale.

## 3.6 Conclusion

According to the calculated SPL in figure 10, most of the hand dryers' peak sound pressures do not exceed 120 dBA. Thus, immediately hearing damages caused by the hand dryer noises are not very likely to occur. However, the peak sound pressure level for different hand dryers varies. Though the hand dryers we measured do not exceed the hazard level, there is no guarantee that all hand dryers are not harmful to ears.

# 4 Discussion and Future Works

## 4.1 General Discussion

In this report, the noise levels of various models of hand dryers are measured. The measured SPL indicates that hand dryers' noise levels do not exceed the 120 dBA threshold; thus, immediate hearing damage is not likely to occur. However, we also noticed that the closer we are to the hand dryers, the larger the SPL will be. When children are using the hand dryers, they are closer to the exhaust port than adults. Therefore, they may perceive a higher SPL. Children's hearing systems are also potentially more vulnerable to hearing damages compared to adults'. This finding is consistent with the result in Keegan (2013) that hand dryers could be potentially damaging to children's hearing.

## 4.2 Future Works

The device used to take the sound pressure from the hand dryers can also be used to take other sound measurements. The device can measure not only the sound pressure but also the sound frequency. We /present some further applications of this device.

- Construction Zones
  With the measured SPL, it is possible to indicate the noise level of different construction sites. The result could be used to see whether the measured noise level will cause hearing damage to the workers on the construction sites.

- Firing Gun
  A firing gun can have a peak sound pressure of over 180 dB within a range of 25 centimeters.[3] The measured SPL could help suggest which kind of ear protection. People should wear when using different guns on the shooting ground.

We appreciate Professor George Golin for providing us the valuable thoughts to start up the project and the necessary equipment to build our Arduino based devices. Also, we appreciate Christian Williams and Justin Languido for giving us helpful comments on the project. We also appreciate Professor Richard Scholwin and Professor Pasquale Bottalico for their excellent insights on acoustic analysis.

[3] Rothschild, Dieker, Prante, & Maschke, 1998.

# References


[1] Vishakha W.Rawool (2011) Hearing Conservation: In Occupational, Recreational, Educational, and Home Settings, Thieme.

[2] Nora Louise Keegan, Children who say hand dryers 'hurt my ears' are correct: A real-world study examining the loudness of automated hand dryers in public places, Paediatrics Child Health, pxz046, https://doi.org/10.1093/pch/pxz046

[3] Shari Salzhauer Berkowitz, Hand dryer noise in public restrooms exceeds 80 dBA at 10 ft, Noise Health, doi: 10.4103/1463-1741.153394

[4] McKinley, M. P., OLoughlin, V. D., Bidle, T. S. (2019). Anatomy physiology: an integrative approach. New York, NY: McGraw Hill Education. Rothschild, M. A., Dieker, L., Prante, H., Maschke, C. (1998). Schalldruckspitzenpegel von Schüssen aus Schreckschußwaffen. Hno, 46(12), 986–992. doi: 10.1007/s001060050346