Acoustic Properties Foellinger Great Hall in the Krannert Center for the Performing Arts

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Kate Bruns, Andrew Calhoun, Maddie Horvat, and Nick Nusgart
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Introduction

Foellinger Great Hall

- Seats 2,059 audience members
- We recorded generated sounds from 176 of these seats

Our Goal is to analyze:

- Sound Decay
- Peak Amplitude
- Environmental Factors- Pressure, Temperature, Humidity

Instruments

PCB Equipment:

- Arduino Mega 2560
- BME 680
- Keypad
- Liquid Crystal Display
- Electret Microphone
- GPS
- RTC
- MicroSD Card Reader
- ADC

Experimental Equipment:

- Sony SRS-X11 Bluetooth Speaker
  - 6.1cm X 6.1cm X 6.1cm
  - Frequency transmission range: 20-20,000 Hz
  - 44.1 kHz sampling
- Music Stands
- Electrical Tape

Experimental Set-up

Four data points could be taken for every trial

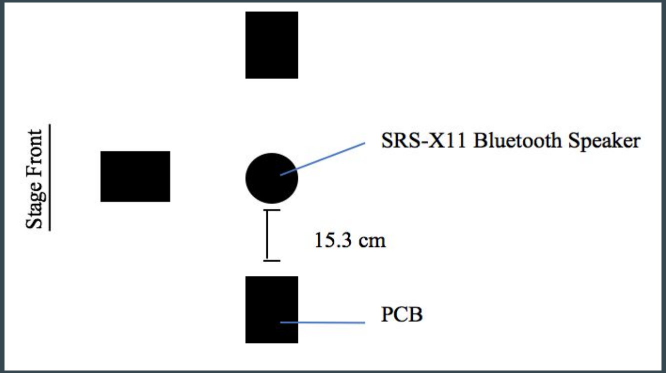
Each PCB started on-stage, moved off stage to a location in the Great Hall, and was moved back on stage for every trial

We created a new coordinate system that could represent every seat in the hall

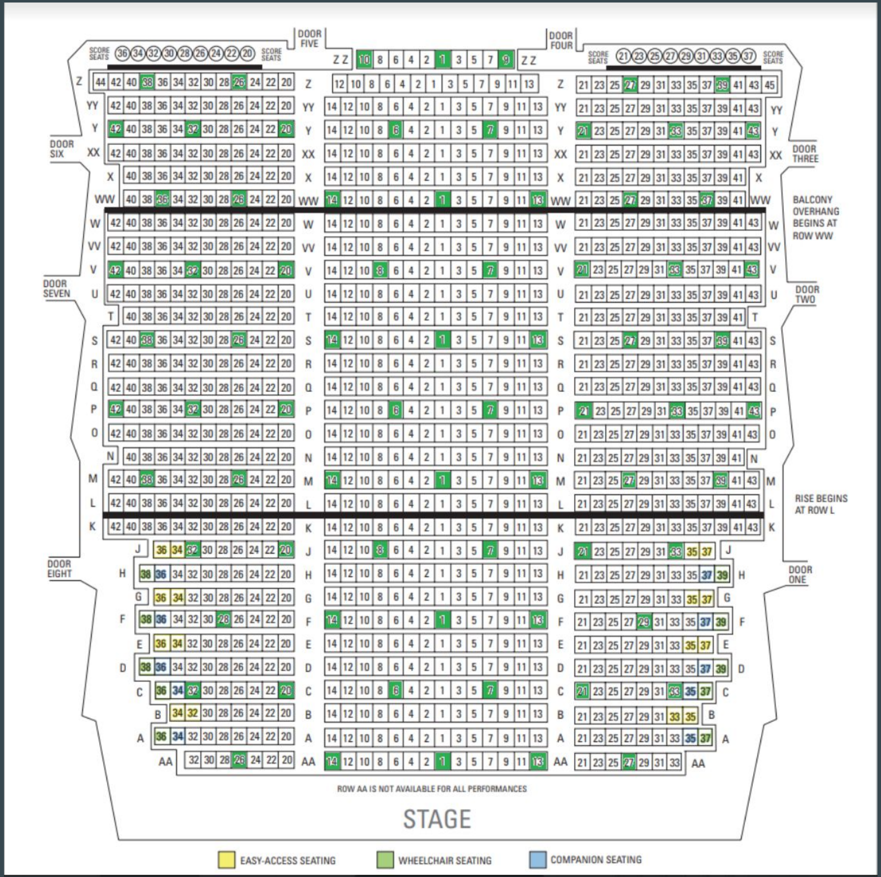
We set up the PCBs on music stands during the recording process, and set the stands in a new location for every trial

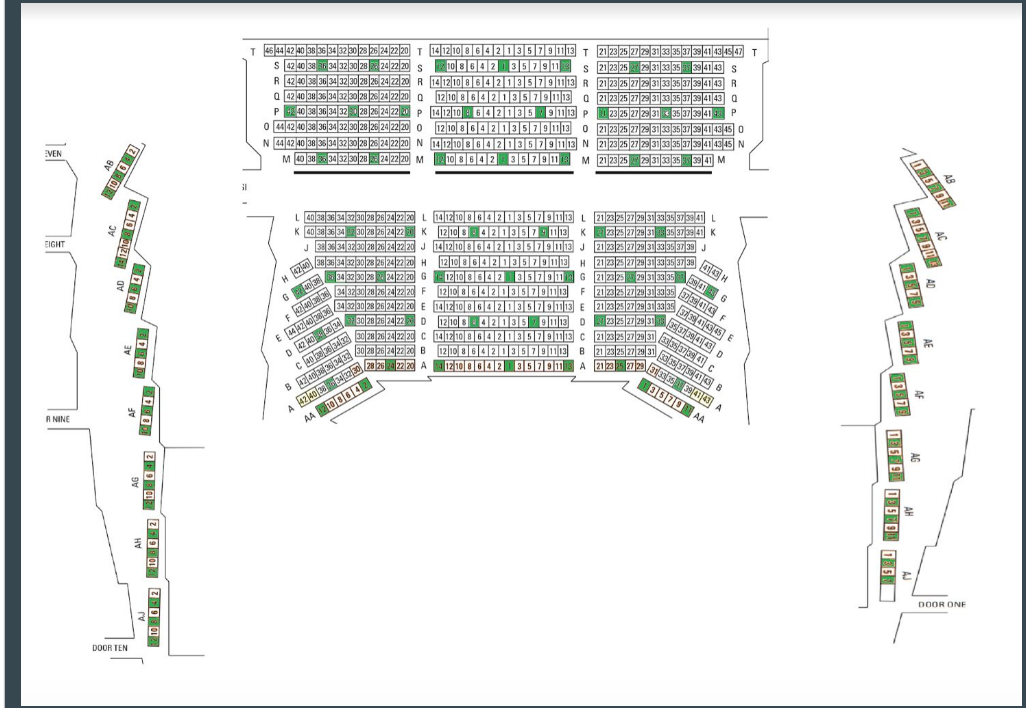
Each trial included a fiducial mark at the start of the run, 15.3 cm from the speaker (see below)

Because each PCB was equidistant, it allowed us to synchronize the recordings



Where we took data





Our Soundtrack

- Sinusoidal Tones at frequencies of 220,440, and 880 Hz were put together in GarageBand
- 9 tones and two fiducial marks were played amidst silence
  - 220, 440, 880 Hz tones--3 of each
  - 440 Hz fiducial marks
- Each tone lasted 4 seconds
- Fiducial Marks lasted 1 second

- Recording Times
  - 0:00-0:01: Fiducial Mark A=440 Hz
  - 0:01-1:04: Silence
  - 1:04-1:08: A=220 Hz tone
  - 1:08-1:16: Silence
  - 1:16-1:20: A=220 Hz tone
  - 1:20-1:28: Silence
  - 1:28-1:32: A=220 Hz tone
  - 1:32-1:40: Silence
  - 1:40-1:44: A=440 Hz tone
  - 1:44-1:52: Silence
  - 1:52-1:56: A=440 Hz tone
  - 1:56-2:04: Silence
  - 2:04-2:08: A=440 Hz tone
  - 2:08-2:16: Silence
  - 2:16-2:20: A=880 Hz tone
  - 2:20-2:28: Silence
  - 2:28-2:32: A=880 Hz tone
  - 2:32-2:40: Silence
  - 2:40-2:44: A=880 Hz tone
  - 2:44-3:40: Silence
  - 3:40-3:41: Fiducial Mark A=440 Hz

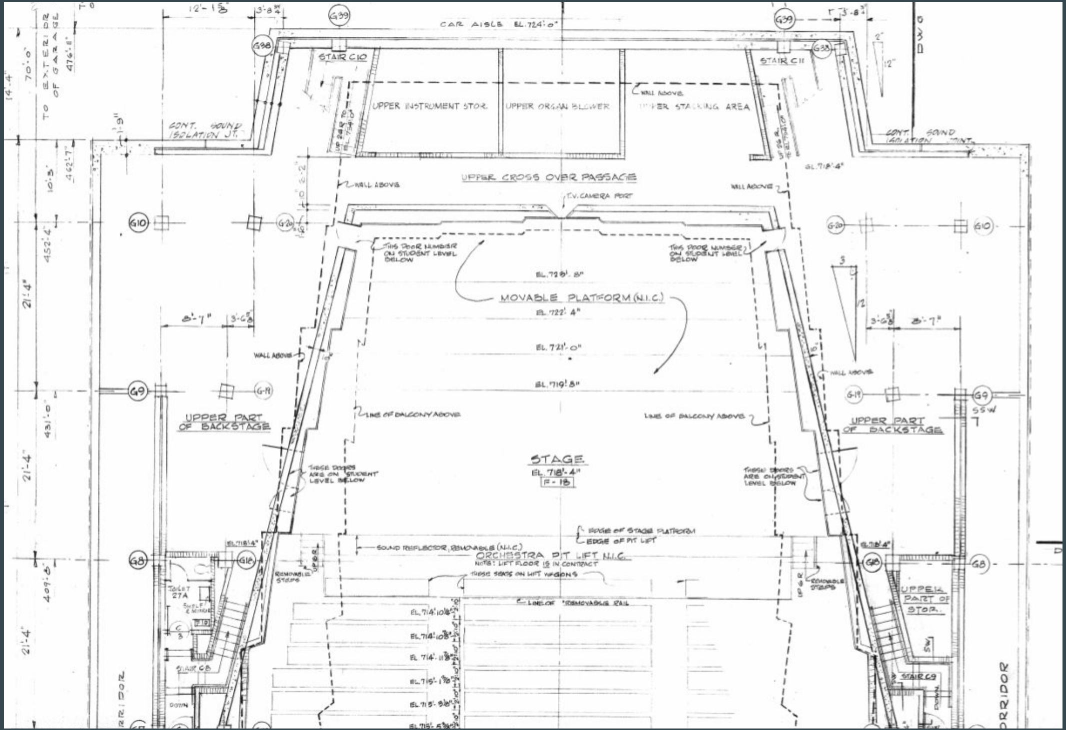
Data Taking Procedure

- Enter Seat #, Row # on PCB
- Press # to start recording
- Press play on audio recording
- Listen for A=440 fiducial mark
- Take PCBs out into the hall to respective locations
- Press Keypad button 1 to instantaneously measure BME 680 data
- Listen for three 220, 440, and 880 Hz tones
- Move PCBs back to stage
- Listen for ending fiducial mark
- Press * to stop

Great Hall Configurations

Choral Balcony Divider

Stage Extension



Data Acquisition Program

Basic Function: The DAQ prompts for a Row# and Seat#, starts a recording, and writes that recording to a file with the time and date. The BME data can be taken on user request.

Set-up Phase:

- Initializes all hardware
- Disables GPS
- Begins communications with SD card
- Retrieves current date from RTC and creates a folder named the current date

Information Prompting Phase:

- Asks for seat and row number of data point
- Checks that no data has been taken at that point
- Constructs file name:
  - kDQrr#cc.dat
  - r=row, c=column

Data Acquisition Program

Recording Phase:

- DAQ configures the ADC to take 10-bit samples at 32 kHz
- Allocates a contiguous temporary file on the SD card to record to, and tells the SD card to begin writing to the start of the file
- Empty and full sample block queues are then initialized,
- User is informed that the recording is about to start
- Starts ADC interrupts
- Simultaneously, a loop is entered in which the DAQ writes any full blocks to the SD card and then puts them back in the empty queue, checks for any errors, listens for user input, and takes an asynchronous BME reading if requested.
- When recording is ended, the DAQ stops ADC interrupts, writes out any remaining blocks, then truncates any unused portions of the file and renames it to its final name.
- Writes out the BME information to a file named "kDQrr#cc.bme".
- Informs the user the the current recording is finished, waits four seconds, and then re-enters the information prompting phase.

Data Analysis- Sound Decay

To get the amplitudes of various frequencies over time, we used a Discrete Time Fourier Transform (DTFT)

We sliced the data into 50 millisecond slices and used NumPy's Real Fast Fourier Transform (FFT) function on them

We fit the decay of amplitude to an exponential function $A(t) \sim e^{-t/\tau}$

The analysis code finds tau values by reading the FFT'ed amplitude data for six seconds, beginning at a point hard-coded into the program.

- this point is the time between the end of the fiducial mark to halfway through the first 440 Hz tone.

Each subsequent run to find a tau value is that base time plus twelve seconds, the length of the four second tone and the eight second quiet gap.

How we fit the decay

Our Offline Analysis Code searched for the frequency with the highest amplitude, and tracked when that amplitude had dropped off 50%

The best fit line was fit to the decay of the frequency following the 50% drop

How the graphs should look

The ln(amp) should start as a straight horizontal line, followed by a sudden drop.

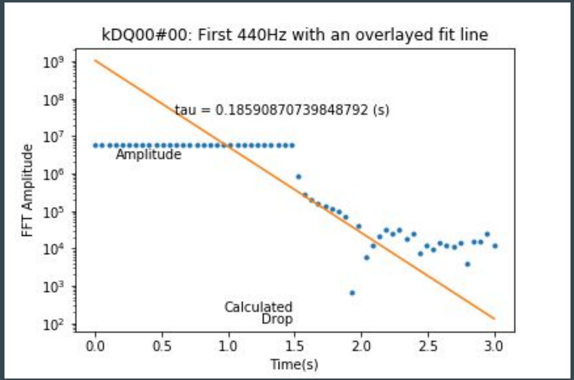
- The horizontal line portion represents the time when the bluetooth speaker is turned on and playing a constant amplitude tone.

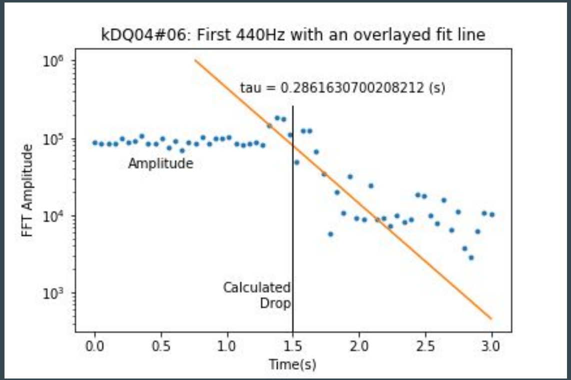
The rest of the graph represents how that frequency resounds in the hall once the speaker tone ends, and this is part of the graph that is needed for the analysis.

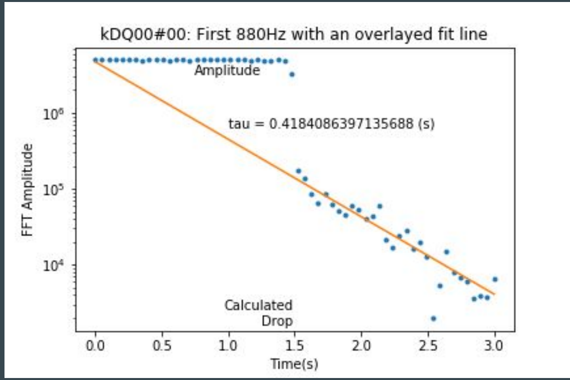
The best fit line is approximating a τ value (the time constant), which is the negative of the reciprocal of the slope.

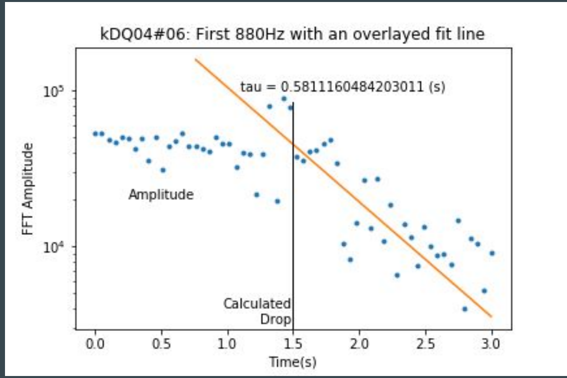
A smaller τ value would mean the sound decays quicker.

Sample Graphs





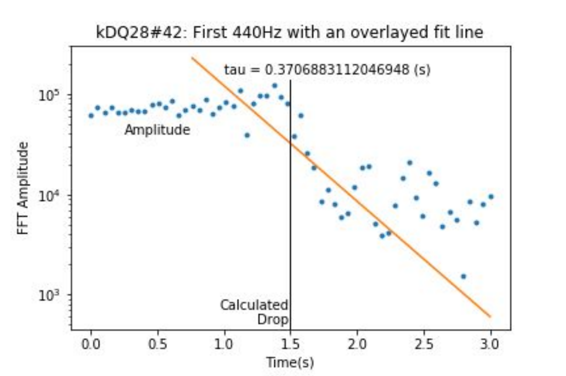


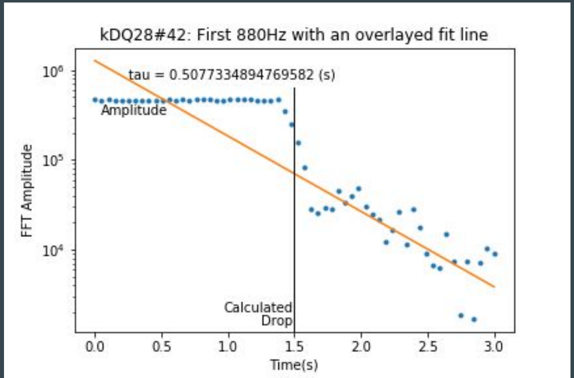


00#00 is the control value, 15.3 cm from the sound source.

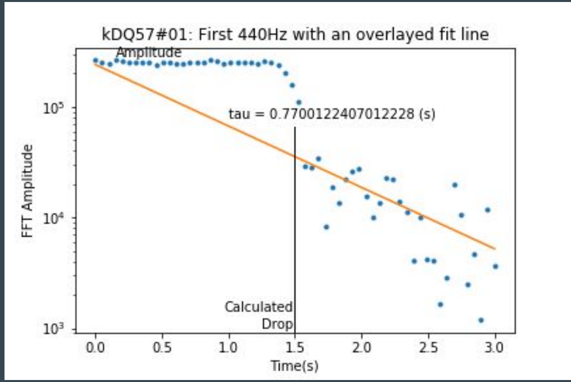
04#06 is in the front on the far right side of the main floor

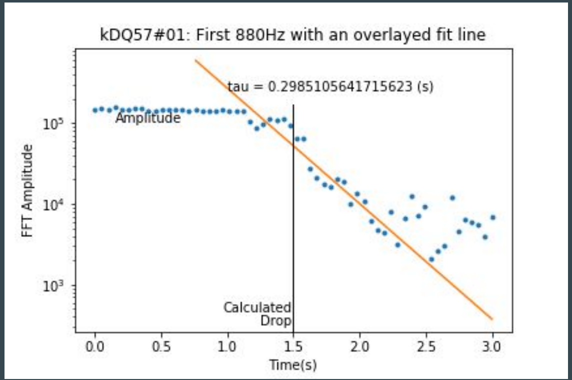
28#42 is in the back of the main floor on the far right side



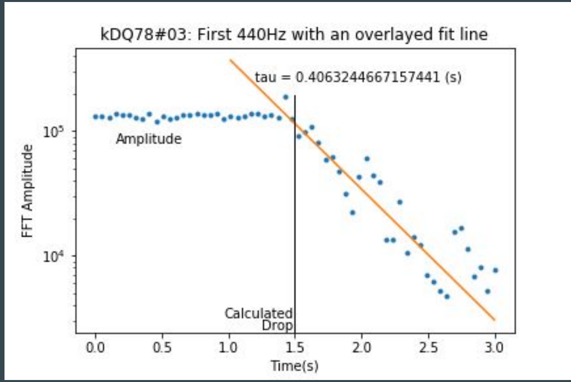


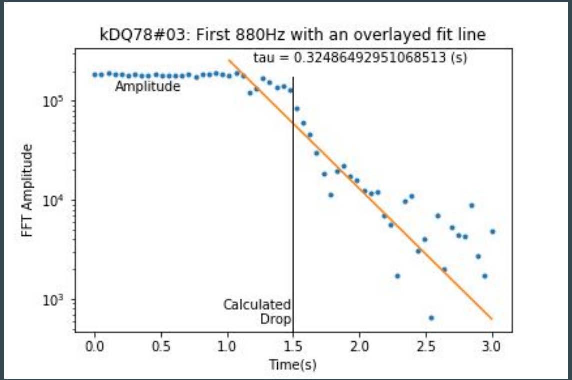
57#01 is in the center of the balcony



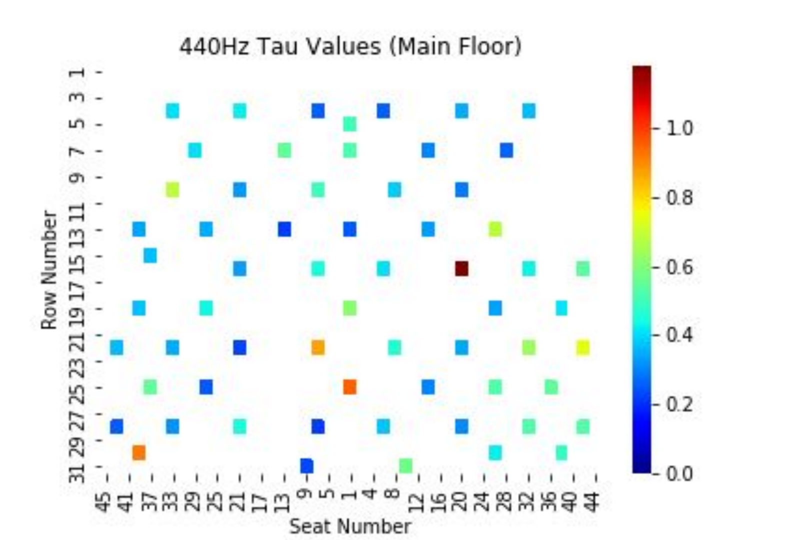


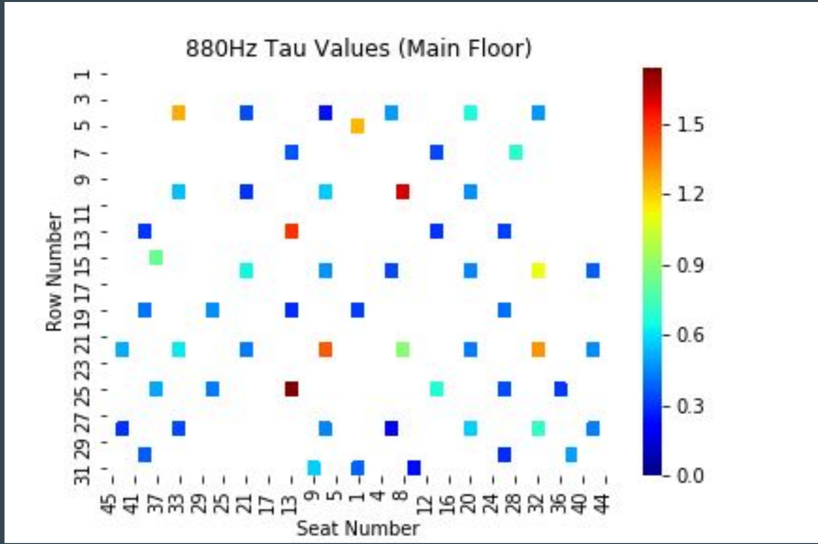
78#03 is in the left side balcony close to the back of the stage



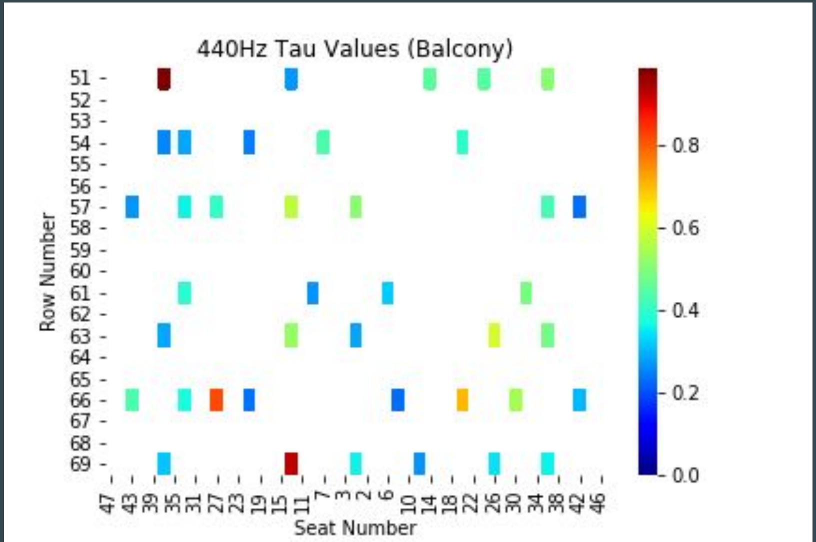


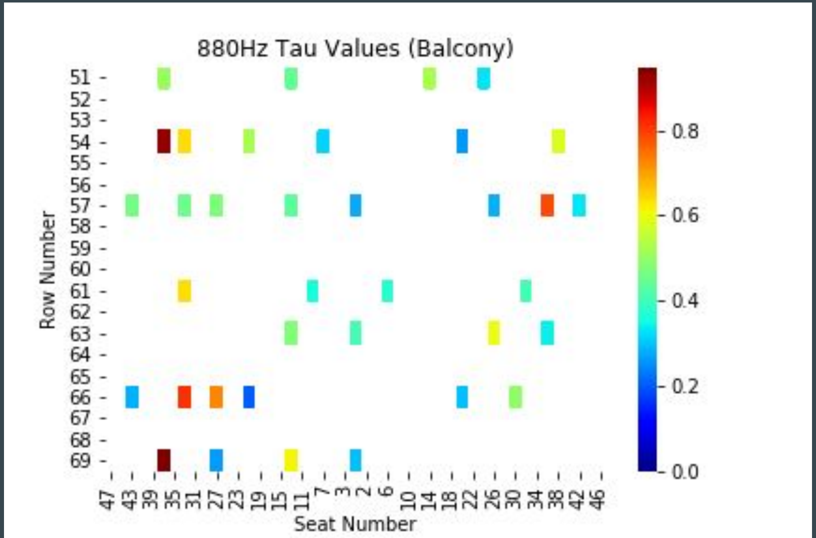
Results- Sound Decay, Main Floor



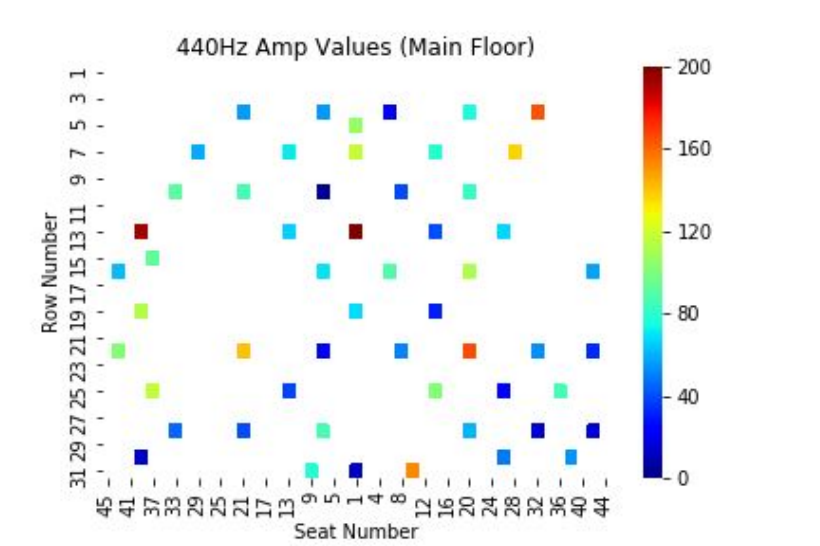


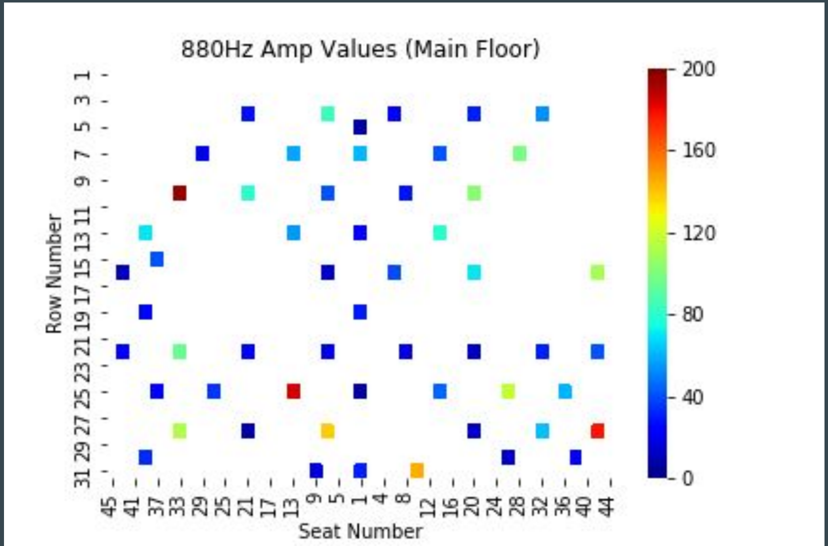
Results- Sound Decay, Balcony



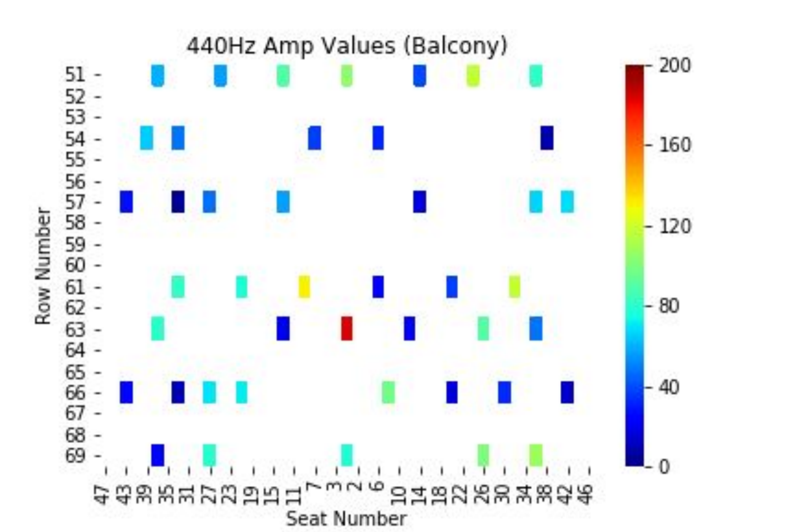


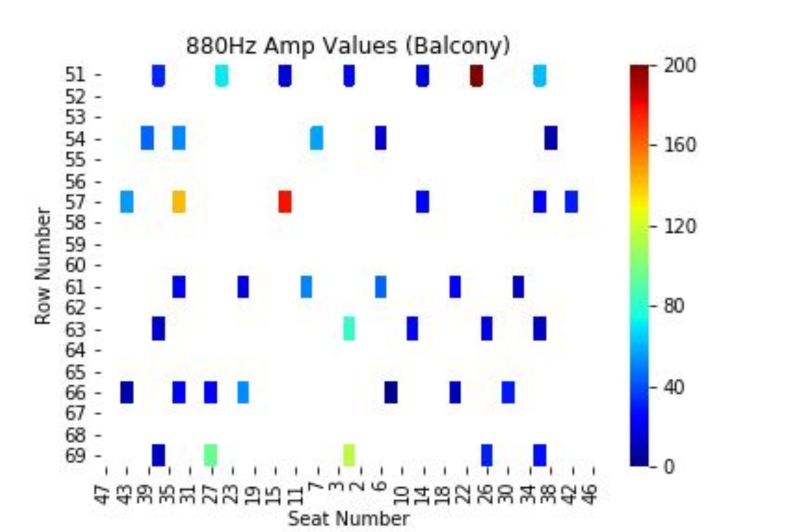
Results- Peak Amplitude, Main Floor



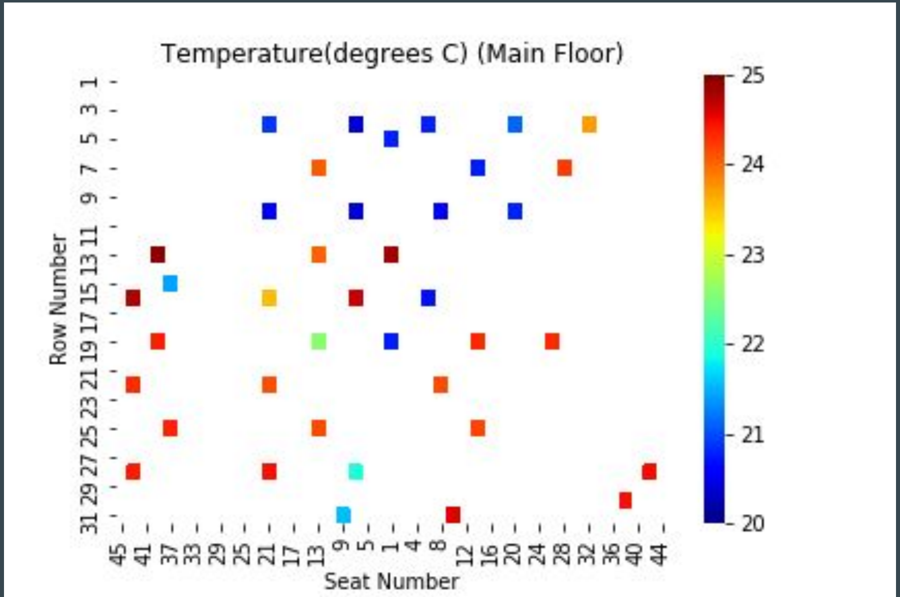


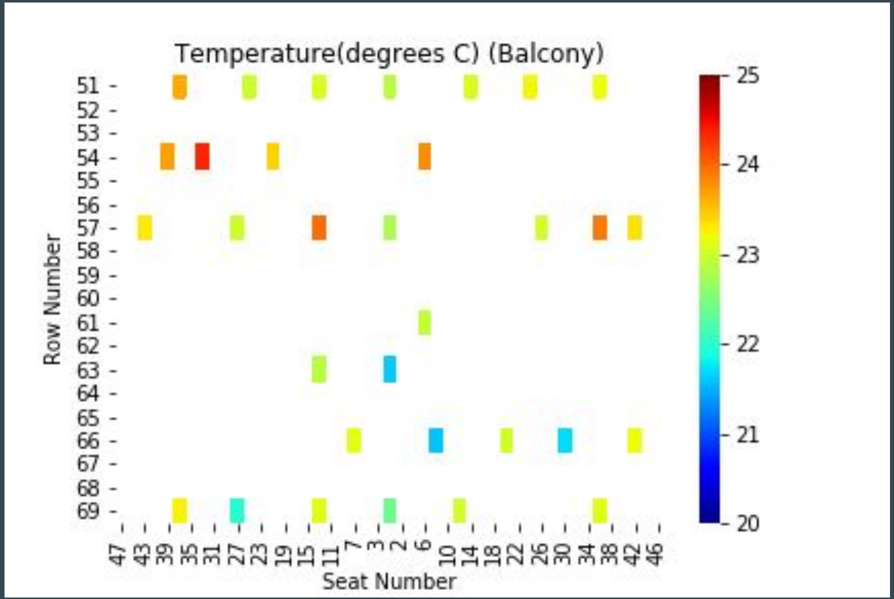
Results- Peak Amplitude, Balcony



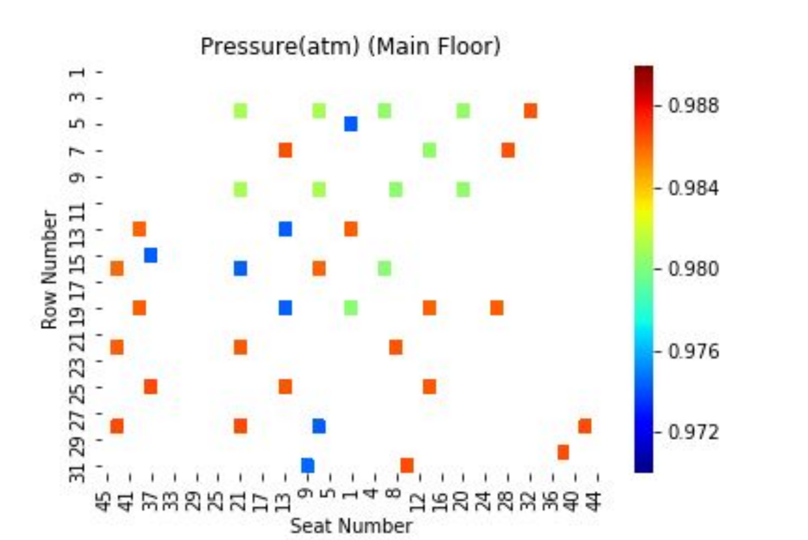


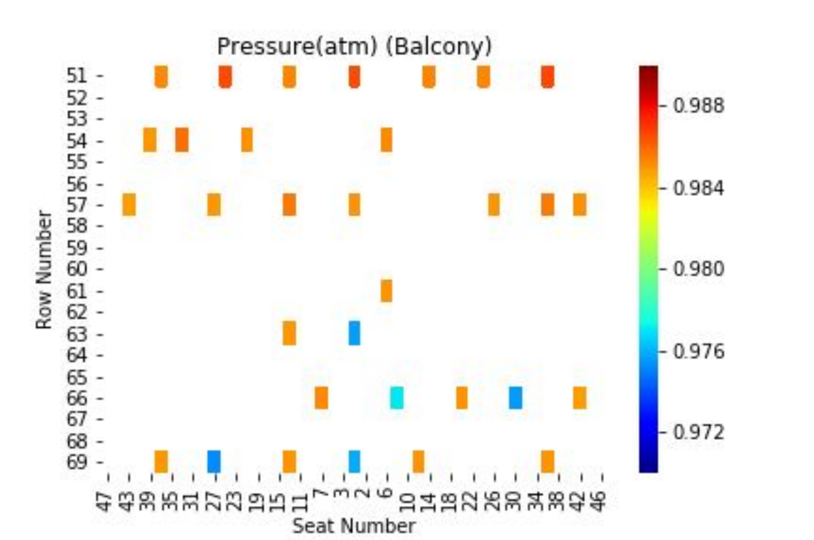
Results- Temperature



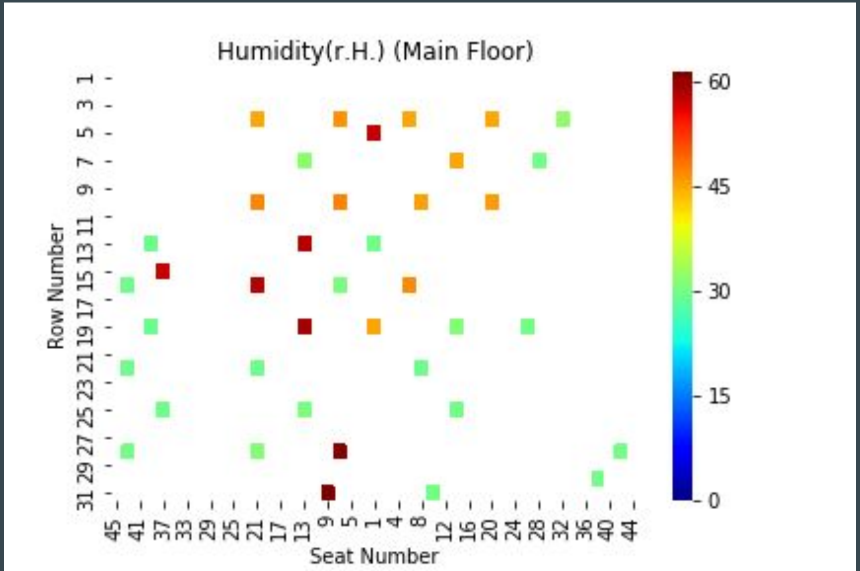


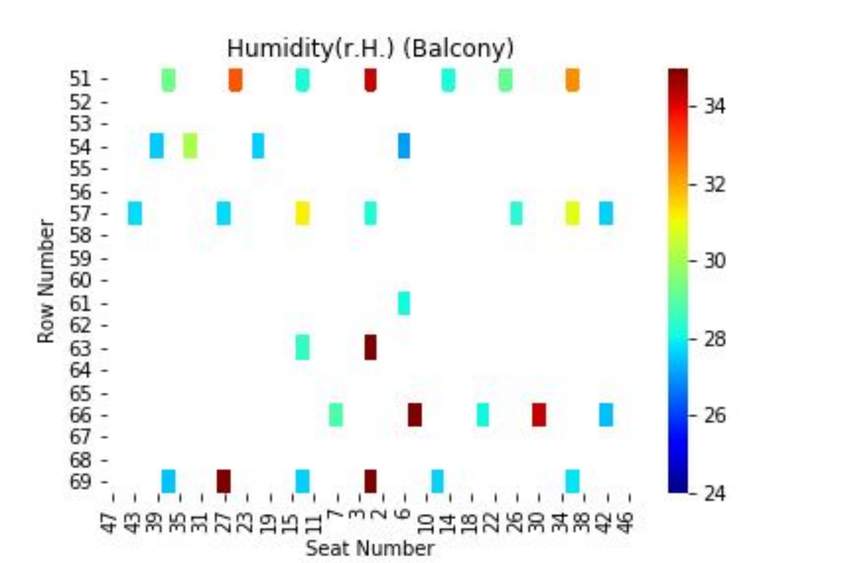
Results - Pressure





Results- Humidity





Experimental Accuracy

The electret microphone

- Sampling Rate:
- Our own ears could hear longer sound decays than what our microphone detected

  Solutions: Louder sound source, clearer microphone detection

Our offline analysis program

- Many of the trials that could be analyzed have odd slopes
- Many other data points had to be thrown out because they were negative when the should only ever be positive, or they deviated too far from the nominal range. We also excluded any tau values that were negative or greater than 30

Solution: A more rigorous analysis program and a lower signal to noise ratio

For Future Research

- Better mics that don’t clip and have a lower RMS value
- More sensitive ADC (more bits, better precision)
- Louder sound source
- Perform more statistical tests on our existing data
- Attempt to fit the tau values and maximum amplitudes to some model

References

https://krannertcenter.com/about-center/our-venues/foellinger-great-hall

https://krannertcenter.com/sites/krannertcenter.com/files/GreatHallMain.pdf

https://krannertcenter.com/sites/krannertcenter.com/files/GreatHallBalcony.pdf

https://www.adafruit.com/