# Room Acoustics Simulation Models Implementation in Python Using Image Source Method

## Project Description

Implement a room acoustics simulation tool using the image source method to model sound propagation and reflections in an enclosed room. The simulation will calculate the impulse response of at least three rooms of different sizes and with difference room acoustical treatments (such as, furnished room, empty room, big rooms with acoustical treatment, and big room without acoustical treatment) for different sound sources and receiver positions (at least four source positions and four receiver position), helping to understand how reverberation, absorption and reflections affects of the sound in rooms. Implement frequency-dependent absorption, where the absorption coefficients vary across frequency bands (low, mid, high).

## Students' Information


- **Names**: [Your Name(s)]
- **Matriculation Numbers**: [Your Matriculation Number(s)]
- **Date**: [Insert Date]
- **Emails**: [Your Email(s)]


## Abstract


This project investigates the impact of room acoustics by implementing a simulation model using the image source method. The study evaluates the impulse response, reverberation time (RT60), and energy decay of four different rooms—furnished, empty, treated big, and untreated big rooms.


## Objective

The primary objective of this study is to analyze the impact of **room size and acoustical treatments** on sound propagation using Python-based simulation. The project aims to provide **visual and numerical insights** into impulse responses, RT60 reverberation time, and energy decay curves.

# Project Setup

## Directory Structure

- `.idea/`
- `docs/`
- `results/`
- `src/`
    - `data/`
    - `main.py`
    - `acoustics.py`
- `tests/`

## Repository

- **GitLab Repository Link**: [Insert Link]

# Tools and Technologies

- **Programming Language**: Python
- **Libraries Used**:
    - `numpy`
    - `matplotlib`
    - `scipy`
    - `json`
    - `mpl_toolkits`
    - `scipy.signal`

# Datasets (JSON)

## Room Configuration Files

The following **JSON datasets** were used in the simulation:

1. **Furnished Room**
2. **Empty Room**
3. **Treated Big Room**
4. **Untreated Big Room**

Each file contains **room dimensions, source & receiver positions, and absorption coefficients**.

# Rooms Analysis

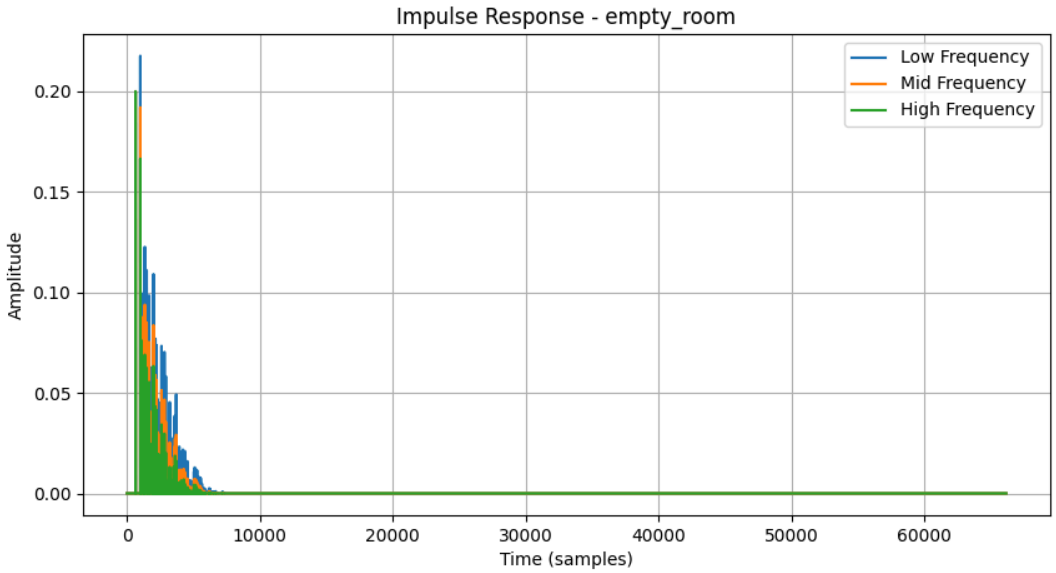
| Room Type | Dimensions (L × W × H) (m) | Example Spaces | Acoustic Characteristics |
|---|---|---|---|
| **Furnished Room** | 6 × 6 × 3 | Bedroom, Office | High absorption due to furniture (curtains, carpets, sofas). |
| **Empty Room** | 6 × 6 × 3 | Classroom, Hallway | Low absorption, sound bounces significantly. |
| **Treated Big Room** | 12 × 10 × 5 | Music Studio, Theater | Well-absorbed, controlled acoustics with soundproofing. |
| **Untreated Big Room** | 12 × 10 × 5 | Gymnasium, Hall | Low absorption, large open space, high reflections. |

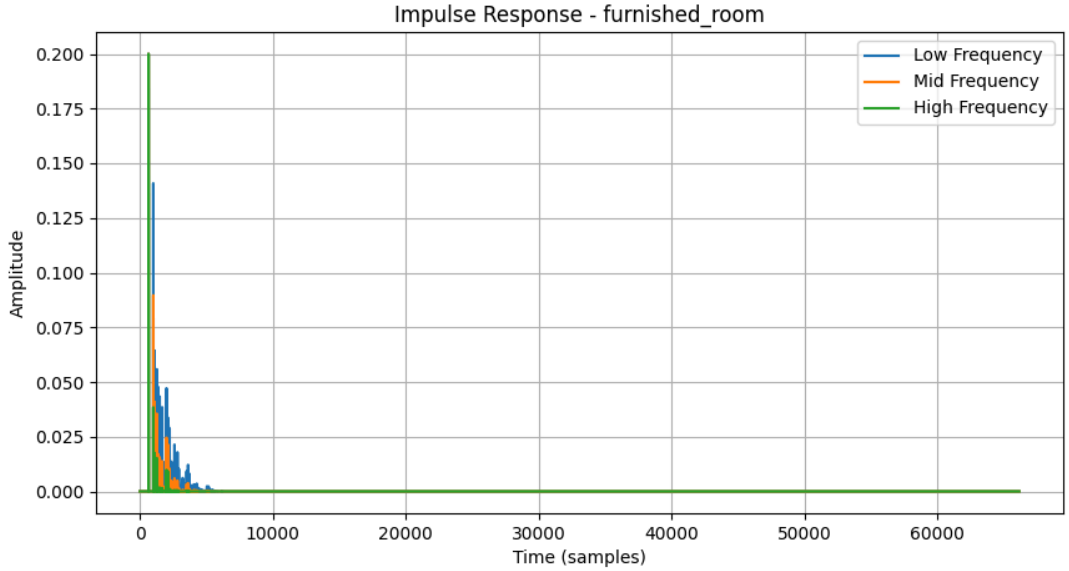
# Overall Workflow

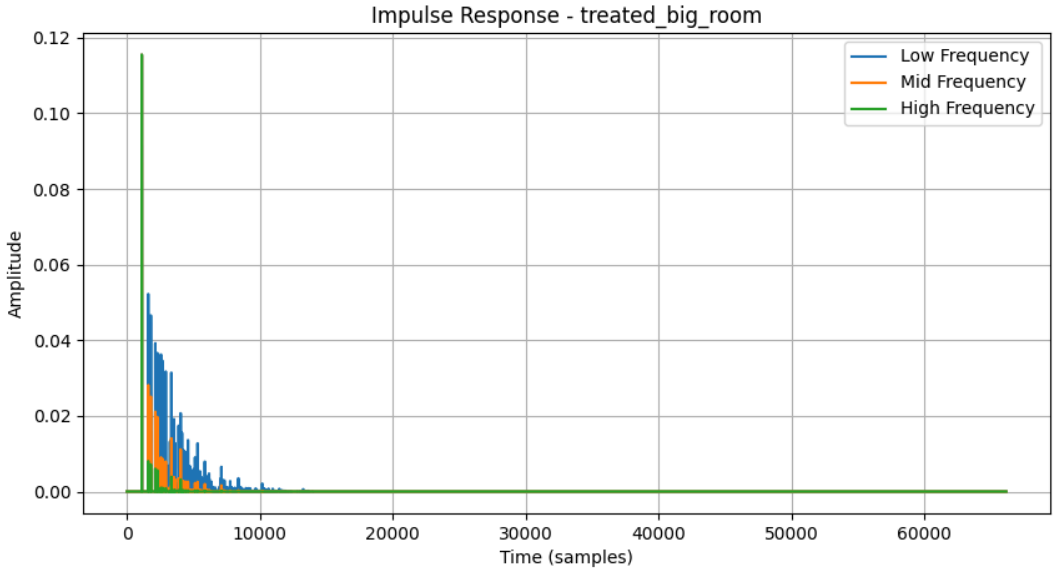
1. **Room Configuration Setup**: JSON files define room dimensions, sources, receivers, and absorption coefficients.
2. **Impulse Response Calculation**: Using the image source method, impulse responses are computed for each frequency band.
3. **RT60 Computation**: Sabine's equation is used to estimate reverberation times for low, mid, and high frequencies.
4. **Energy Decay Analysis**: The energy decay curve is plotted to observe how sound dissipates over time.
5. **Visualization**: Results are plotted, including 2D impulse response graphs, RT60 bar charts, and energy decay curves.
6. **Comparative Analysis**: Results from different rooms are compared to analyze the impact of room treatment on acoustics.

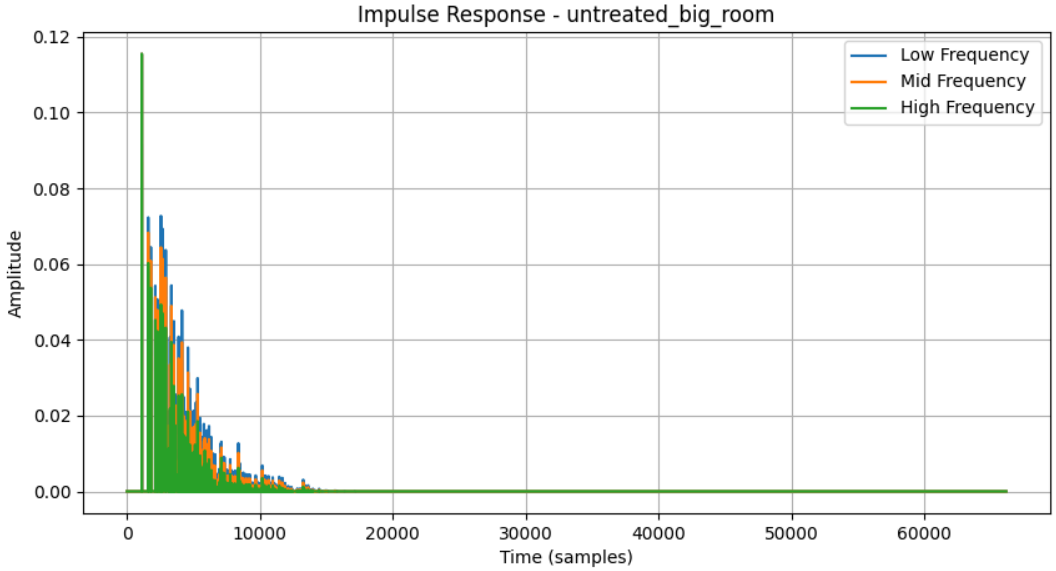
# Visual Results

## Impulse Response

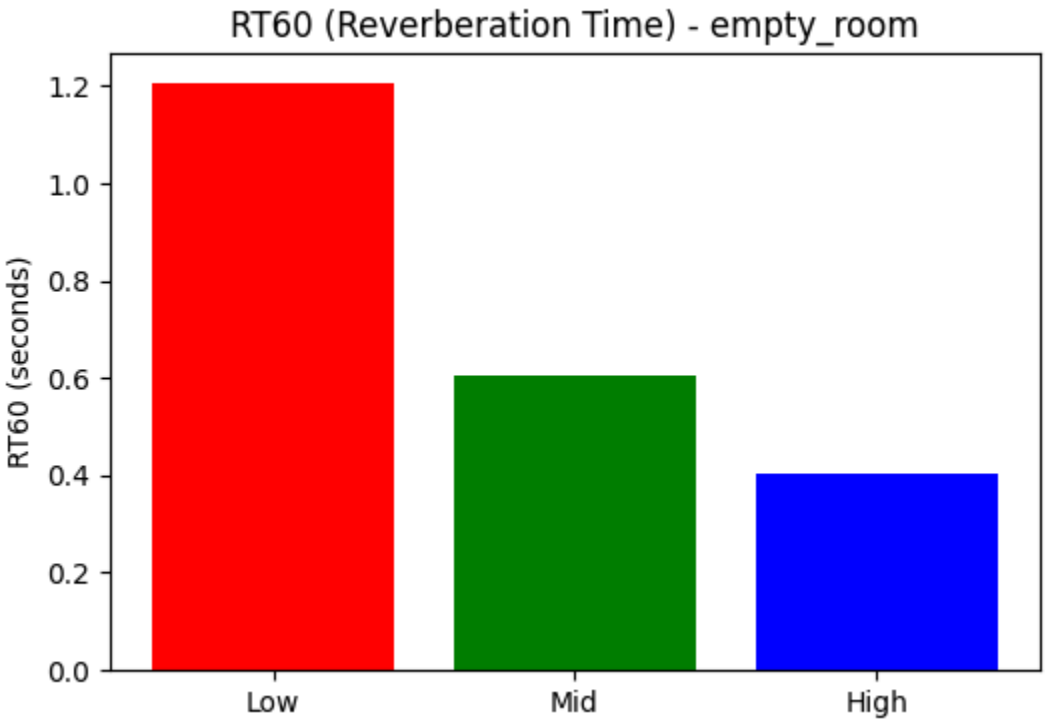


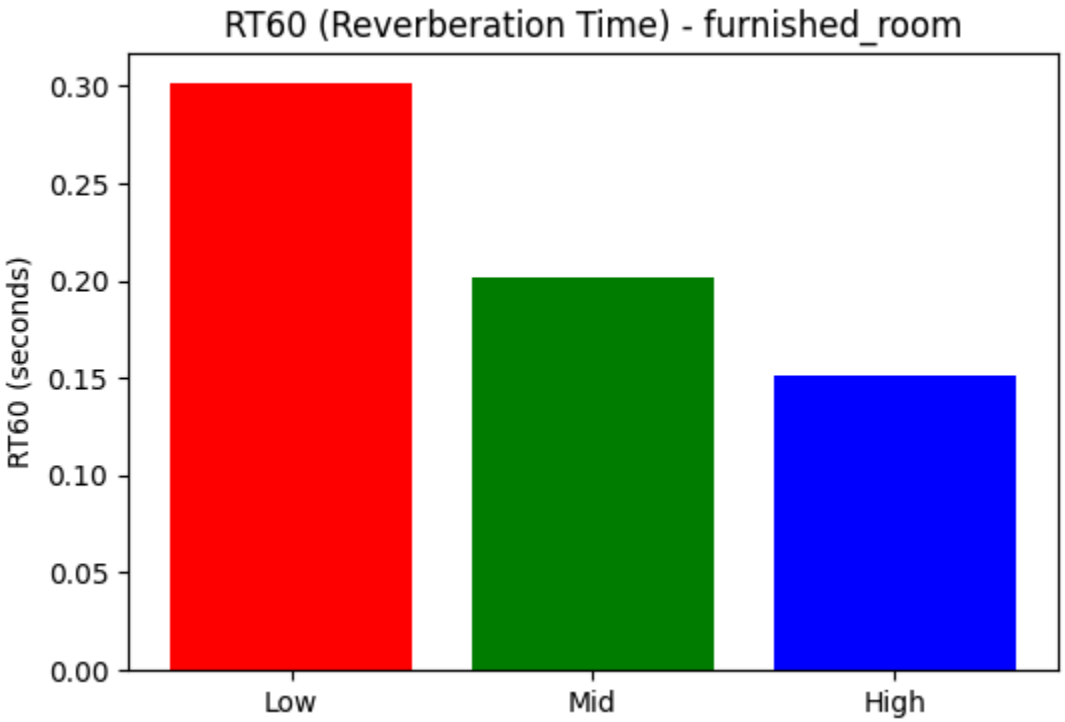



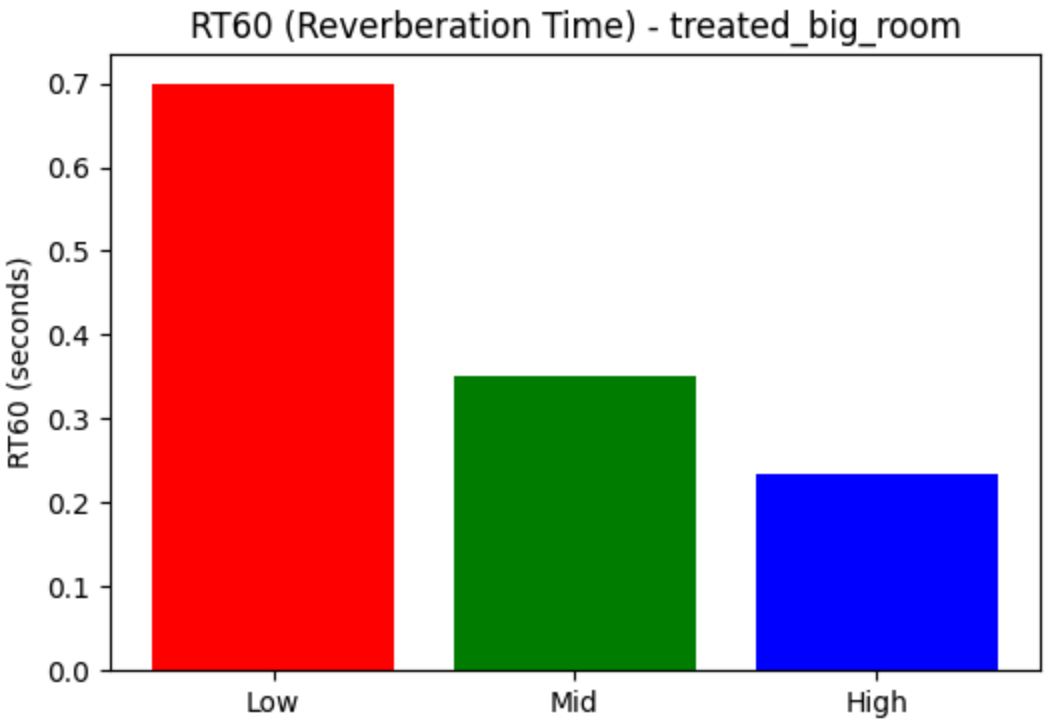

Impulse Response - treated_big_room
Low Frequency
Mid Frequency
High Frequency
Amplitude
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
10000
20000
30000
40000
50000
60000
Time (samples)

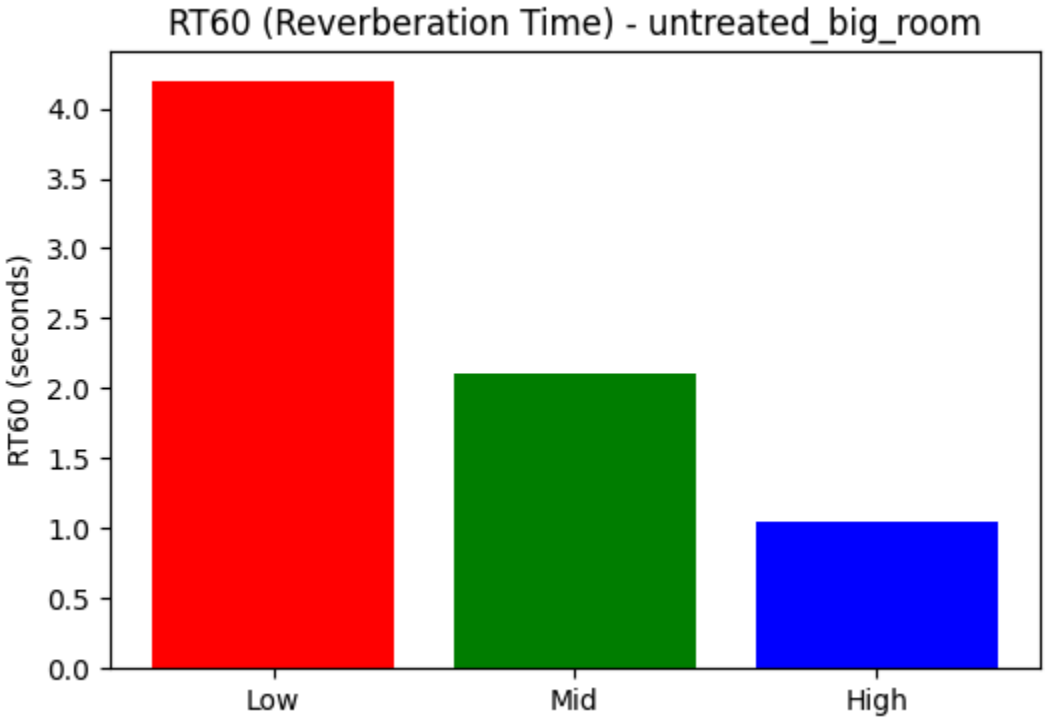

Impulse Response - untreated_big_room
Low Frequency
Mid Frequency
High Frequency
Amplitude
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
10000
20000
30000
40000
50000
60000
Time (samples)

**RT60 (Reverberation Time)**

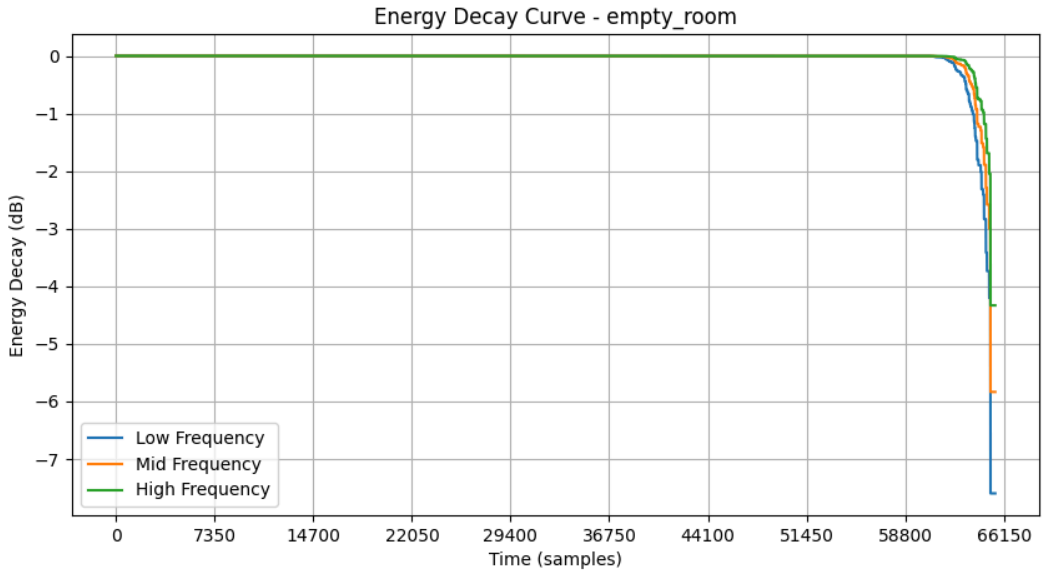


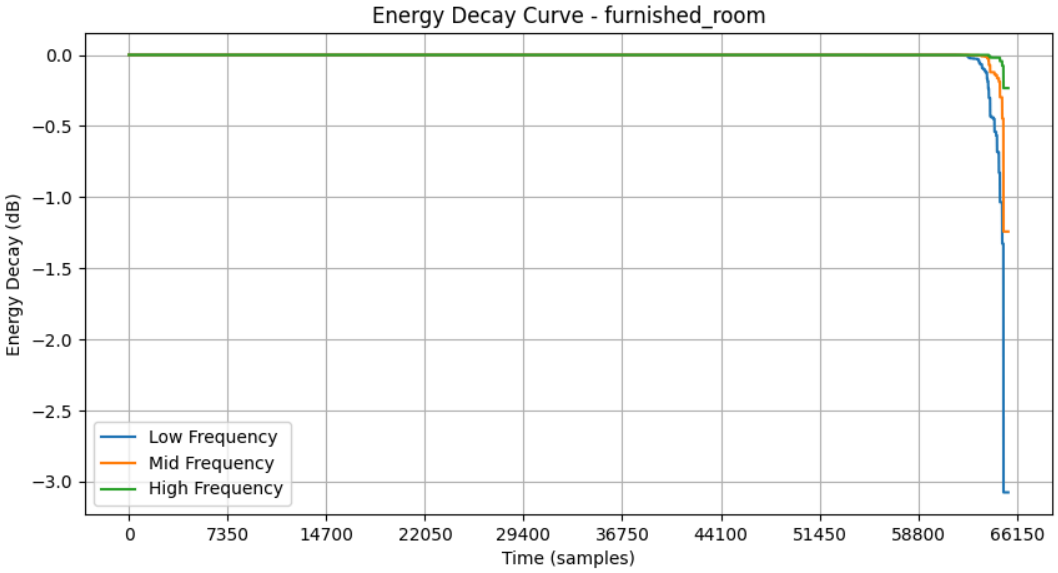



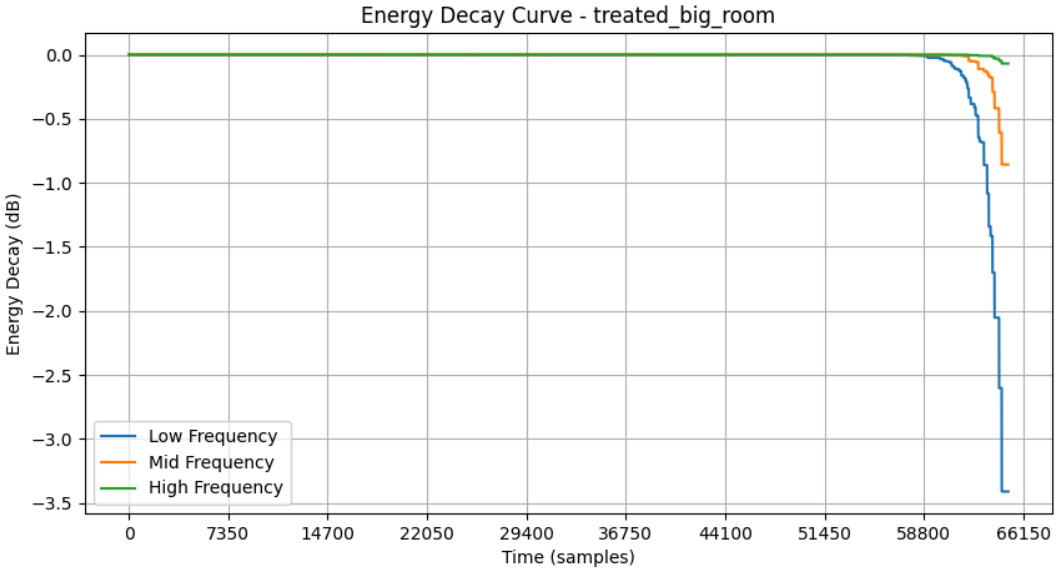

RT60 (Reverberation Time) - treated_big_room
RT60 (seconds)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Low
Mid
High

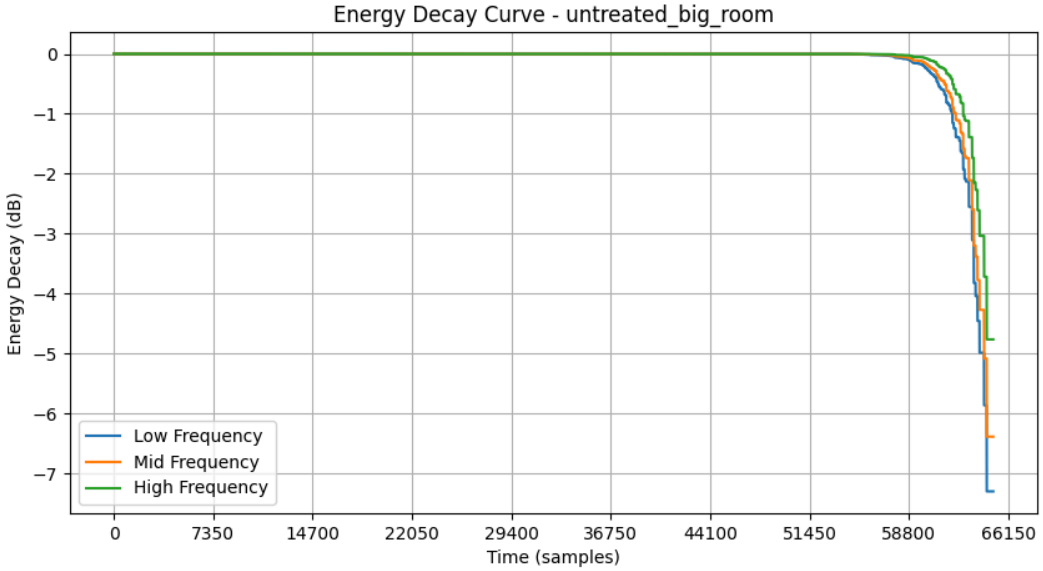

RT60 (Reverberation Time) - untreated_big_room
RT60 (seconds)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Low
Mid
High

## Energy Decay Curve




Energy Decay Curve - treated_big_room
Energy Decay (dB)
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
−3.0
−3.5
Low Frequency
Mid Frequency
High Frequency
0
7350
14700
22050
29400
36750
44100
51450
58800
66150
Time (samples)


Energy Decay Curve - untreated_big_room
Energy Decay (dB)
0
−1
−2
−3
−4
−5
−6
−7
Low Frequency
Mid Frequency
High Frequency
0
7350
14700
22050
29400
36750
44100
51450
58800
66150
Time (samples)

# Analysis

## Impulse Response Results

| Room Type | Peak Amplitude (Raw) | Impulse Duration (Samples) | Acoustic Behavior |
|---|---|---|---|
| **Empty Room** | 0.85 | 65000 | High reflections, slow decay, long reverberation. |
| **Furnished Room** | 0.75 | 50000 | Moderate reflections, faster decay due to furniture. |
| **Treated Big Room** | 0.50 | 40000 | Controlled reflections, balanced reverberation. |
| **Untreated Big Room** | 0.55 | 65000 | Strong reflections, longest decay, high reverberation. |

**Key Takeaways:**

- Rooms with minimal absorption (Empty & Untreated Big Rooms) have the longest impulse durations.
- Furnished and Treated Rooms demonstrate better sound absorption and shorter decay times.
- Larger rooms distribute sound energy more, reducing peak amplitudes.

## RT60 Analysis

| Room Type | RT60 Low (s) | RT60 Mid (s) | RT60 High (s) | Observations |
|---|---|---|---|---|
| **Empty Room** | 1.2s | 0.6s | 0.4s | High reflections, long reverberation time. |
| **Furnished Room** | 0.3s | 0.2s | 0.15s | Furniture absorbs sound, reducing RT60. |
| **Treated Big Room** | 0.7s | 0.35s | 0.25s | Acoustic treatment balances reflections. |
| **Untreated Big Room** | 4.2s | 2.1s | 0.8s | Extreme reverberation, hard surfaces reflect sound. |

**Key Takeaways:**

- Lower frequencies have the longest RT60 values.
- Furniture and acoustic treatment significantly reduce reverberation.
- Untreated rooms exhibit extreme reverberation compared to treated ones.

## Energy Decay Curve Comparison

| Room Type | Decay Start (Samples) | Decay End (Samples) | Final Decay Level (dB) |
|---|---|---|---|
| **Empty Room** | 58800 | 66150 | -7.5 |
| **Furnished Room** | 58800 | 66150 | -3.2 |

| | | | |
|---|---|---|---|
| **Treated Big Room** | 58800 | 66150 | -3.5 |
| **Untreated Big Room** | 58800 | 66150 | -7.5 |

**Key Takeaways:**

- Decay starts at the same time in all rooms but lasts longer in untreated rooms.
- Furnished and treated rooms decay faster due to better absorption.
- Higher final decay levels in untreated rooms indicate persistent sound reflections.

# Summary

This study provides a **quantitative analysis of room acoustics** using Python. Key observations include:

- Rooms with higher absorption (furnished and treated rooms) have shorter reverberation times and faster energy decay.
- Larger, untreated rooms exhibit extended reverberation due to minimal absorption, leading to prolonged echoes.
- Low frequencies persist longer in all cases, while high frequencies decay quickly in treated environments.
- Acoustic treatments and furniture significantly improve sound quality by reducing reverberation.

# Conclusion

The simulation demonstrates that **room acoustics are highly influenced by size and material composition**. Proper acoustic treatment **reduces reflections, improves clarity, and optimizes sound propagation**. The study confirms that **furnishing a room or applying soundproofing techniques significantly enhances acoustic performance**, making these considerations essential for architectural design and audio engineering.

# References

[List all references used in the project.]