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

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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`

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**.
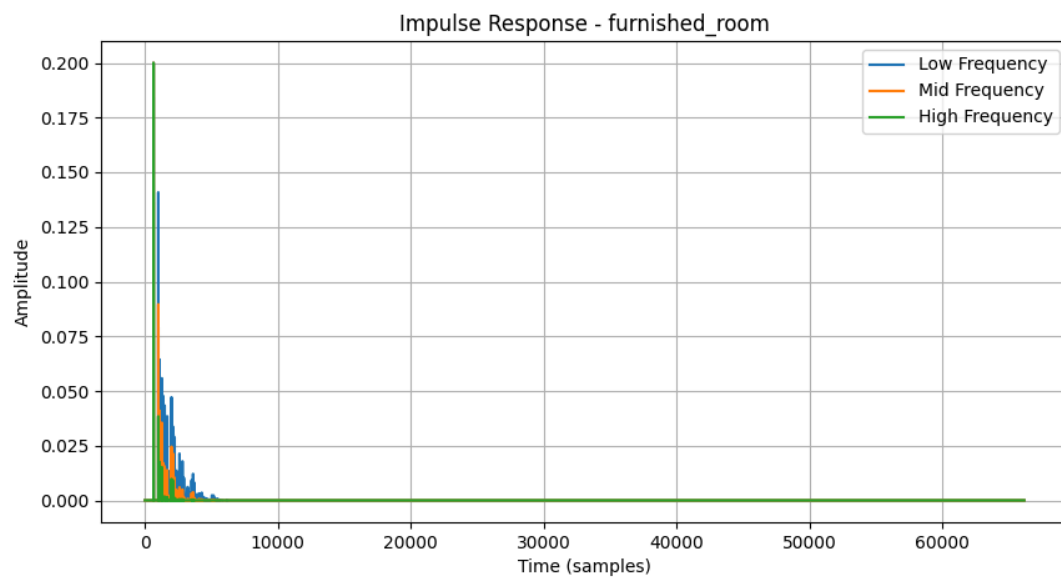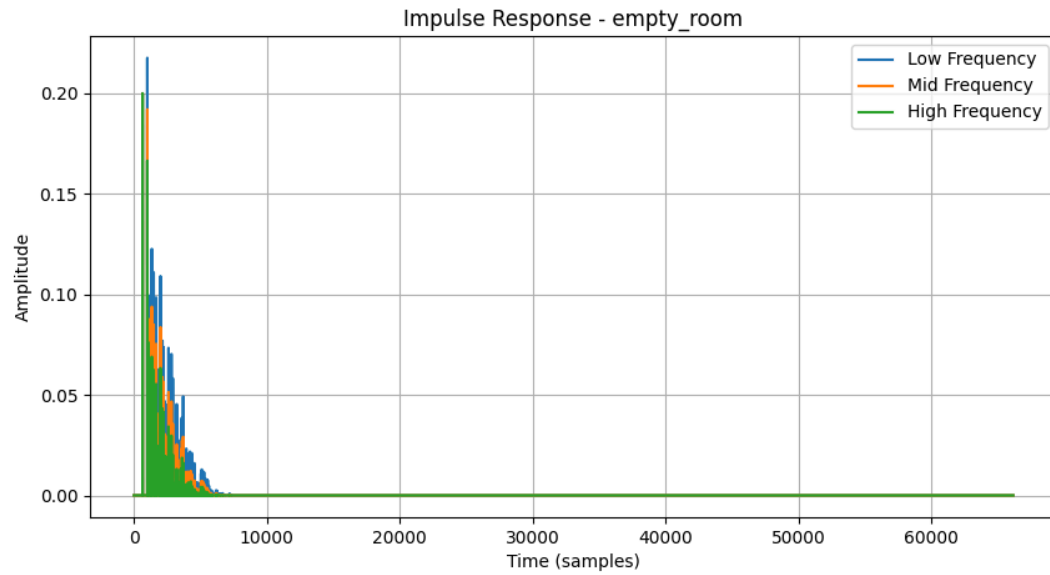
Rooms Analysis

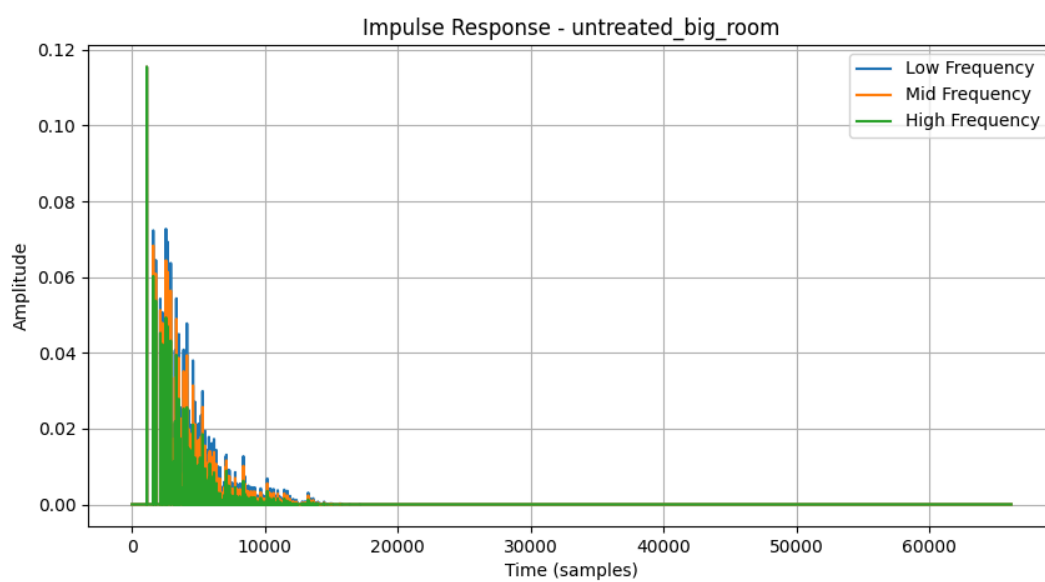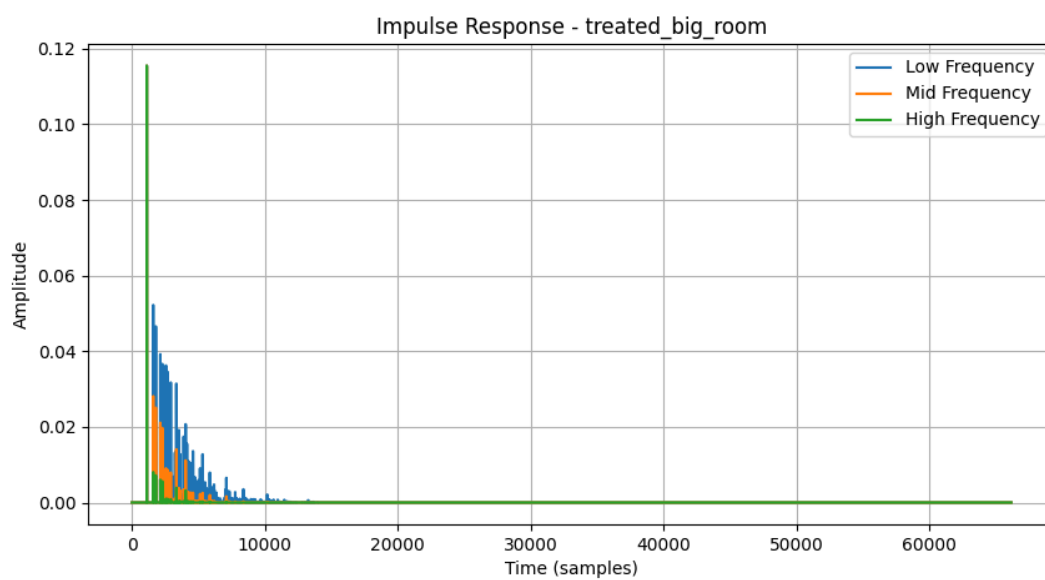| Room Type	Dimensions (L × W × H) (m)	Example Spaces	Acoustic Characteristics
Furnished Room	6 × 6 × 3	Bedroom, Office	High absorption due to furniture (curtains, carpets, sofas).
Empty Room	6 × 6 × 3	Classroom, Hallway	Low absorption, sound bounces significantly.
Treated Big Room	12 × 10 × 5	Music 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.
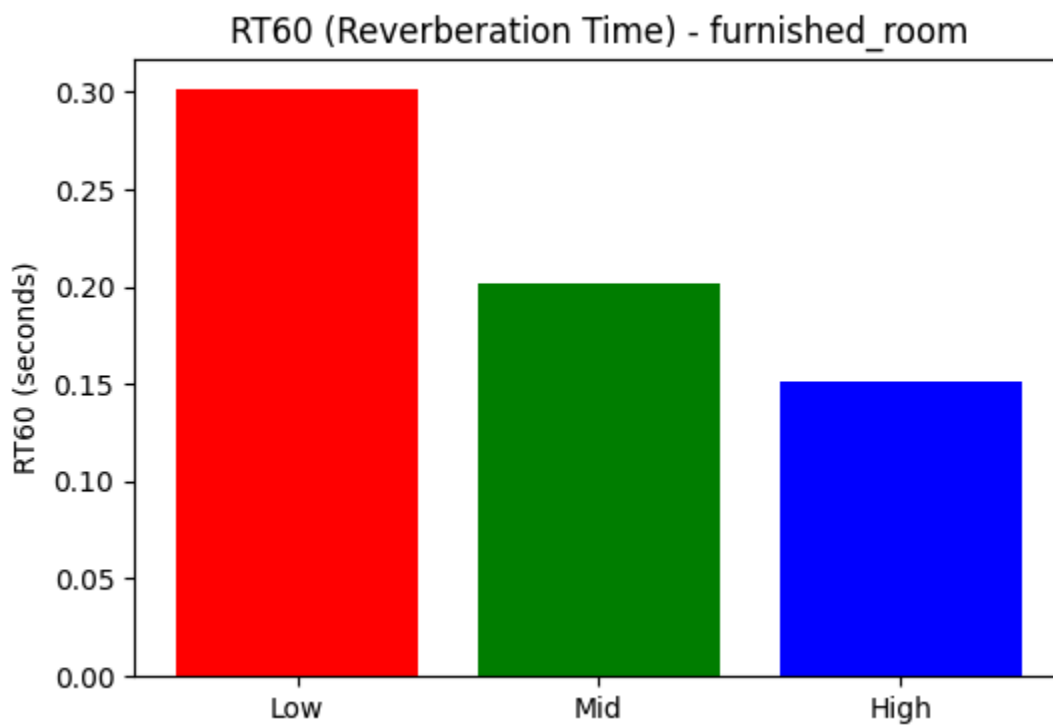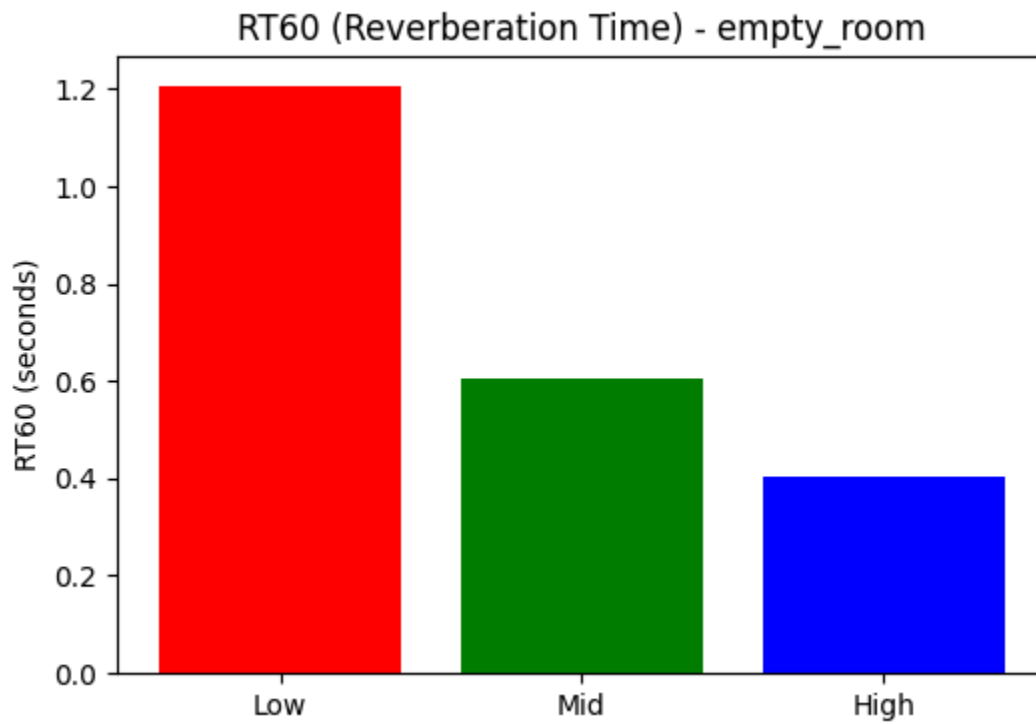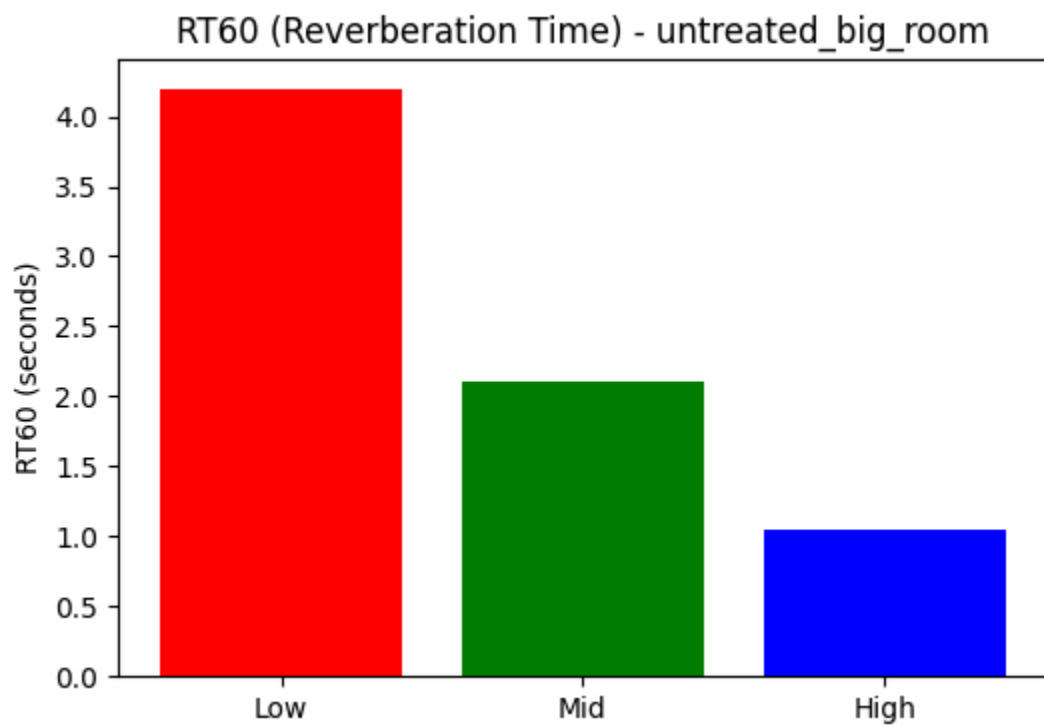
Visual Results

Impulse Response

Impulse Response - empty_room

Impulse Response - furnished_room

Impulse Response - treated_big_room

Impulse Response - untreated_big_room

RT60 (Reverberation Time)

RT60 (Reverberation Time) - treated_big_room

RT60 (Reverberation Time) - untreated_big_room

Energy Decay Curve

Energy Decay Curve - empty_room

Energy Decay Curve - furnished_room

Energy Decay Curve - treated_big_room

Energy Decay Curve - untreated_big_room
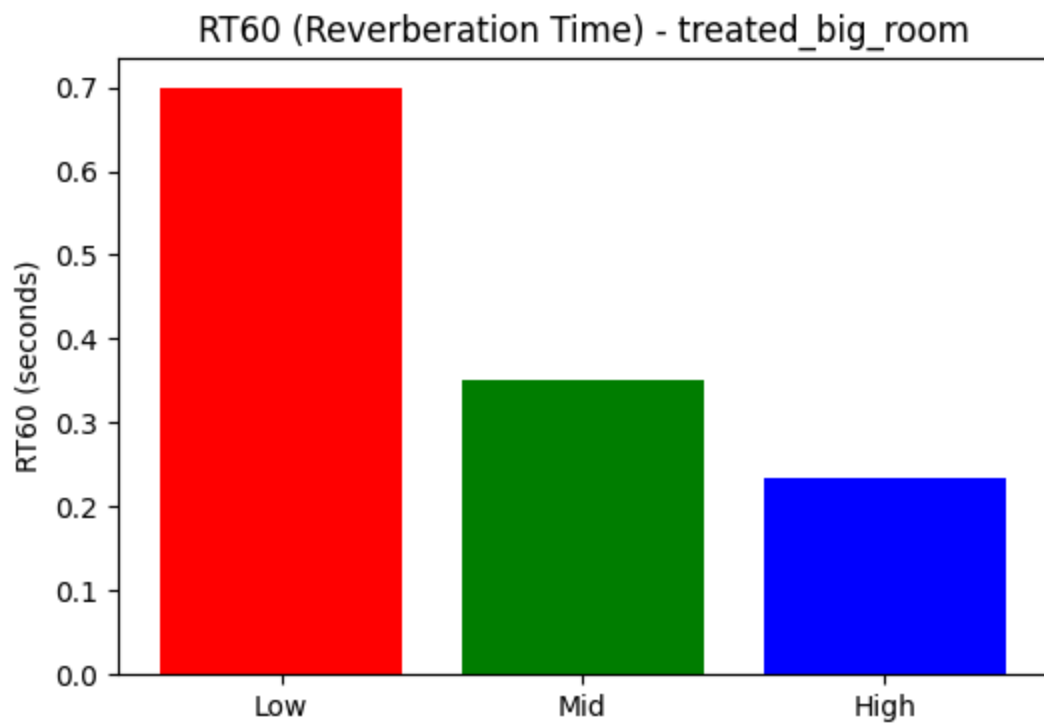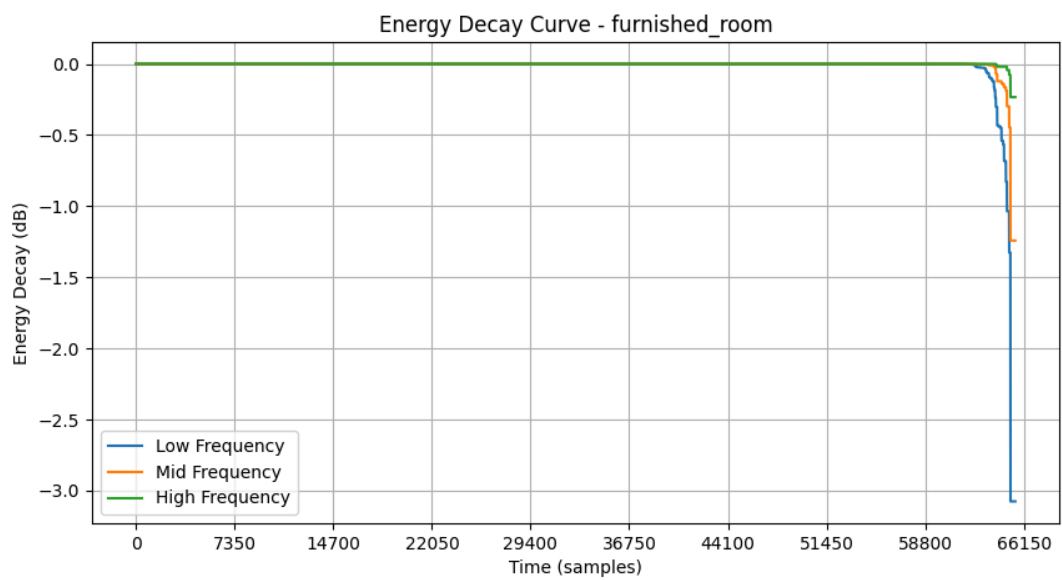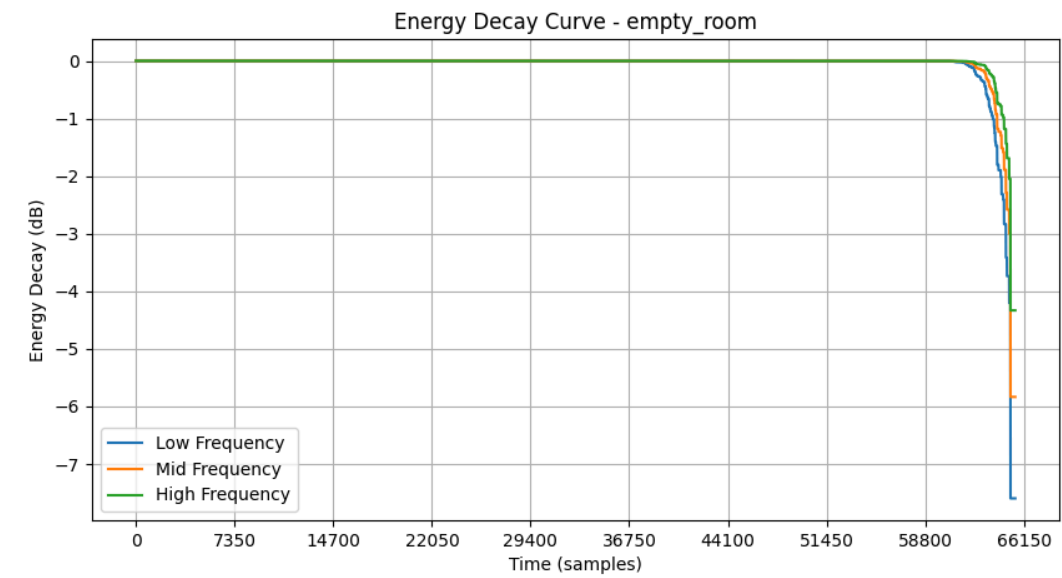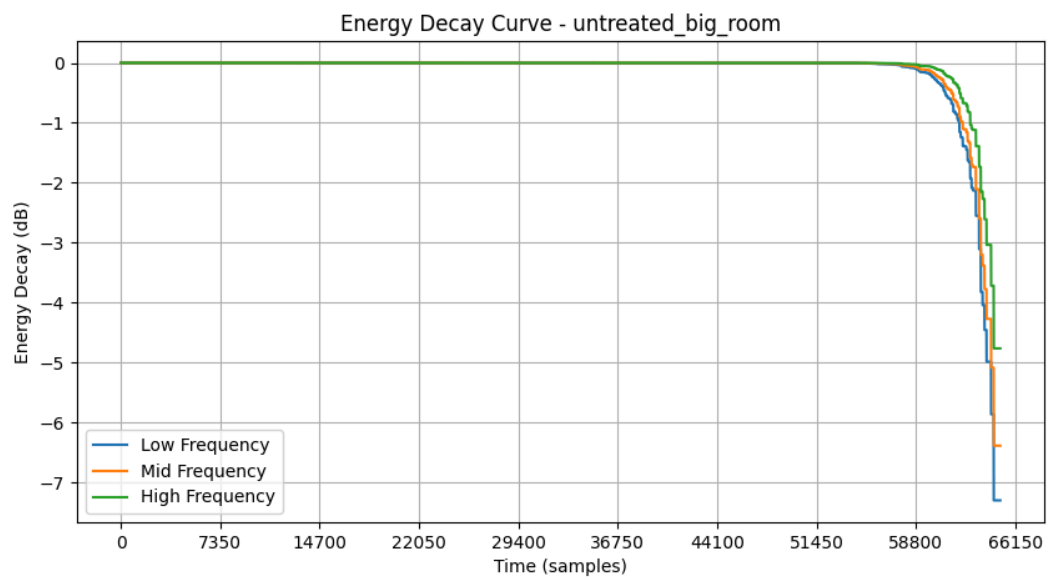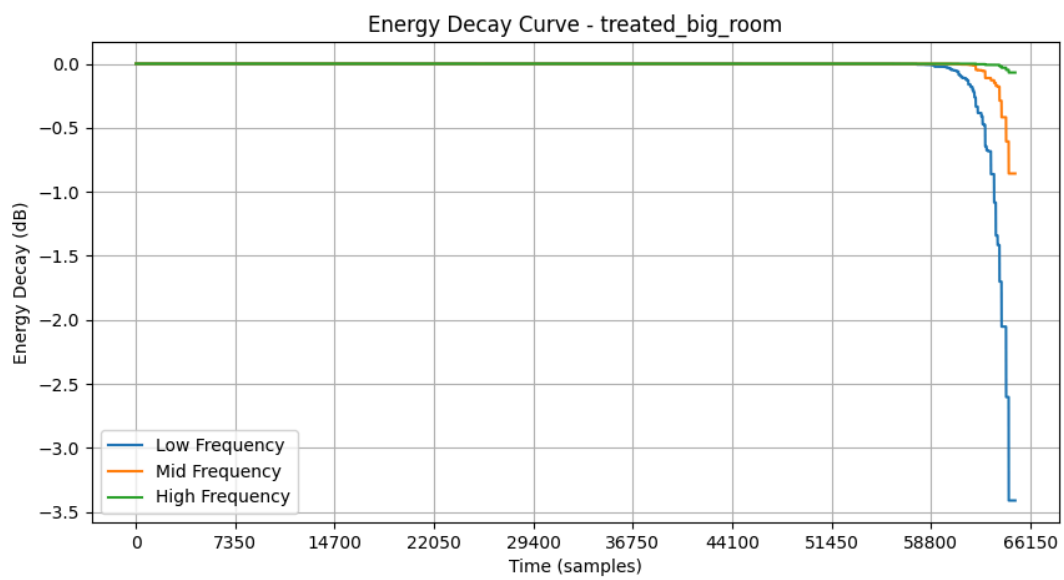
Analysis

Impulse Response Results

Room Type	Peak Amplitude	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

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- J. B. Allen and D. A. Berkley. Image method for efficiently simulating small-room acoustics. J. Acoust. Soc. Am., 65:943-950, 1979.