Project ID: UREP31-088-2-028

QNRF

UREP FINAL REPORT

Project Report

This report will be used to technically evaluate the project for UREP Competition and other purposes. Please follow the scheme given in the box below, and use Arabic or English (depending on the language of the project).

Abstract: Noise pollution in urban areas is a significant environmental issue with serious effect on health and quality of life. Road traffic contributes 66% to the overall noise pollution in urban areas. Prolonged exposure to noise can affect hearing and cause Permanent Threshold Shift (PTS). Controlling noise levels in urban environments is important factor in avoiding adverse effects on health, as highlighted by the World Health Organization (WHO). Noise from road traffic can be reduced by use of outdoor measures such as noise barriers and indoor measures such as double-glazed windows. The development of end-user tools for predicting the noise levels in the planning stage helps the end-users significantly in the selection and adoption of right measure. Beside the scarcity of such tools in the hands of end-users, there is a gap between the output resulting from such tools and what is appreciated and understood by a typical end-user. A typical end-user would appreciate such tools significantly better if the outputs can be translated in a playable sound that he/she can compare with other sounds. The proposed project will fill this gap by developing a web-based tool for the community to use for relating the sound metrics with recorded sound to relate the metrics with heard signals. The tool will be freely accessible for users to listen to signals recorded from real environments, such as sound from the side of a road or a room facing a road, and see the corresponding graphs for different metrics. The tool will help the community to appreciate the metrics, realize differences of perceptions between users, besides helping users to sense the approximate effect of introducing control measures such as noise barriers. The users will be able to do this by playing noise signals from the web interface, for the cases of before and after the use of control measures. The developed website of the tool will be supplied by results of noise measurements carried out by this project and from the literature for cases corresponding to noise from road traffic. It will also show the processed data from signal processing carried out in the project. The project will be carried out by students from different majors: Civil Engineering; Mechanical Engineering; Computer Science and Computer Engineering, who will be developing their research skills beside furthering their knowledge in an important application. The students will be collaborating and working on different work-packages of the project and making use of their knowledge from courses in Environmental Engineering, Signal Processing, and Web development. Beside the web application, the outcome of project will be disseminated to the relevant stakeholder in Qatar and to professional engineers. The project will be supervised by two academics with strong research experience

and track-record in working with the industry in Qatar in the field of Noise and Vibration.

Objectives/Significance: Environmental noise is defined as unwanted or harmful outdoor sound created by human activities, such as noise generated by road traffic and construction activities [1]. Sound is generated due to a series of pressure changes resulting from surface vibrations or fluid flow in an elastic medium [2]. Noise pollution in urban areas is a significant issue with effect on health and quality of life. Road traffic contributes 66% to the overall noise pollution in urban areas [3]. Prolonged exposure to noise can affect hearing and cause Permanent Threshold Shift (PTS) [4]. Reducing noise levels in urban environments is a serious issue and there are defined limits to avoid adverse effects on health [5]. There are also number of guidelines and manuals for the assessment of these levels, see [6] for example for the transit noise and vibration assessment. Noise from road traffic can be reduced by use of outdoor measures such as noise barriers and indoor measures such as double-glazed windows. The development of end-user tools for predicting the noise levels in the planning stage helps the end-users significantly in the selection and adoption of right measure. Beside the scarcity of such tools in the hands of end-users, there is a gap between the output resulting from such tools and what is appreciated and understood by a typical end-user. A typical end-user would appreciate such tools significantly better if the outputs can be translated in a playable sound that he/she can compare with other sounds.

The main aim of this project is to develop a tool for the community, whether industry or end users, to use for relating the sound metrics (sound levels including maximum, average values, weighted sound levels, etc..) with recorded sound to relate the metrics with heard signals. The tool will be freely accessible for users to listen to signals recorded from real environments, such as sound from the side of a road or a room facing a road, and see the corresponding graphs for different metrics. This tool will not only help the community to appreciate the metrics and realize differences of perceptions between users, but it will also help users to sense the approximate effect of introducing noise counter-measures such as the use of noise barriers and the replacement of single-glazed by double-glazed windows. The users will be able to do this by playing noise signals from the web interface, for the cases of before and after the use of noise countermeasures. To achieve the aim of the project, three objectives have been defined:

Objective 1: Carrying out measurements to collect and analyze noise data from standard cases corresponding to noise from road traffic for cases with and without the use of control measures.

Objective 2: Carrying out a comprehensive signal processing exercise for data extracted from the literature along with the analysis, benchmarking, and comparison against guidelines.

Objective 3: Developing the web-based interface based on data and findings from the measurement exercise and the processing of data from the literature.

The planned web-based interface will fill a significant gap for the community when trying to understand the potential effect of using measures to reduce noise in existing environments. The web-based interface with its multiple functionalities and the relationships between graphs and playable signals will be the first of its kind in Qatar and will set a strong milestone in developing this interface for other applications in the field of environmental noise and vibration. The students working in the project will develop their knowledge on environmental noise, data analysis, signal processing, and development of user interfaces. The project will benefit from the supervisory team with backgrounds in Civil and Mechanical Engineering beside the multi-displinary background of students from Civil Engineering, Mechanical Engineering, Computer Engineering and Computer Science. The project supports the effort in the College of Engineering at Qatar University to engage students in multi-disciplinary projects. It will also support the College of Engineering and Department of Civil and Environmental Engineering, which added Environmental Engineering to the department's name to focus further in this important area and its important topics such as environmental noise and vibration. The work will include collaboration with the Ministry of Environment and Climate Change and in particular the air quality team who have been contacted and showed strong interest in collaboration on this project. The user-interface developed in this project will be extended in the future to similar application on ground-borne noise to support the ongoing work of the investigators with Qatar Rail on ground-borne noise and vibration.

WP1: Data collection and Measurements Methodology

The work in this workpackage involved reading of literature, collection and analysis of measurement's data. The following graphs show the steps used to analyze the effect of double glazing on outdoor noise levels. The first graph presents the acoustic pressure recorded over time with the original window. This time-domain signal is then converted into a frequency spectrum, shown in the second graph, to identify the main noise frequencies present. Using the easements without the double-glazed window frequency domain with the insertion loss form the literature, the reduction is estimated and converted to the time domain for the user to listen and compare.

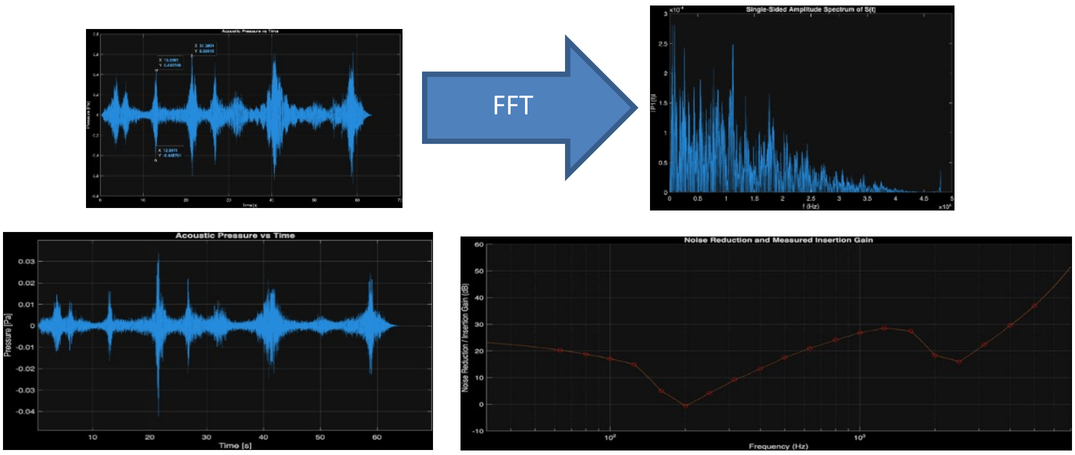
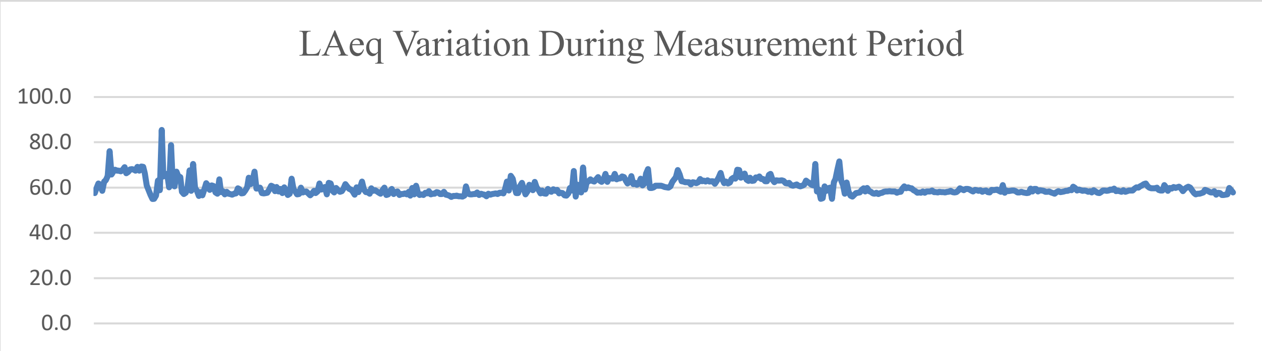


Figure 1

The acoustic pressure signal is first measured in the time domain, where variations in sound pressure over time are observed. The recorded time-domain signal is then transformed into the frequency domain using the Fast Fourier Transform (FFT), allowing identification of the dominant frequency components of the noise. This process is applied to both the original and treated signals. Finally, the frequency-domain results are compared to evaluate noise reduction performance, and the insertion loss is calculated across frequency bands to show how noise reduction varies with frequency.

WP1 Results and Discussion:



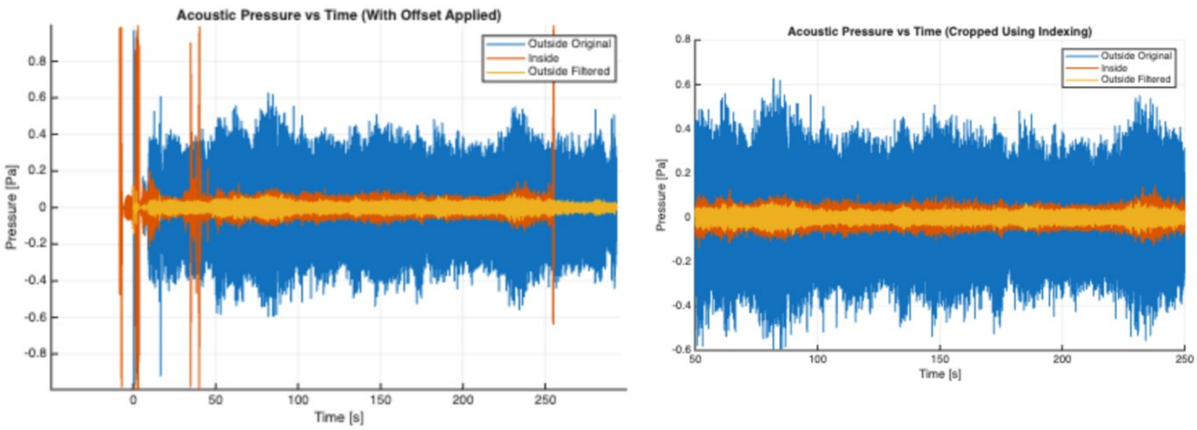


Figure 2

The figure shows the acoustic pressure signals of the outside original, inside, and filtered outside recordings after applying a time offset. The offset allows the signals to be temporally aligned for direct comparison. The outside recording exhibits larger pressure fluctuations, indicating higher noise levels. The inside signal shows lower amplitudes, demonstrating sound reduction inside the building despite the presence of AC noise. The filtered outside signal appears smoother confirming the effect of noise filtering.

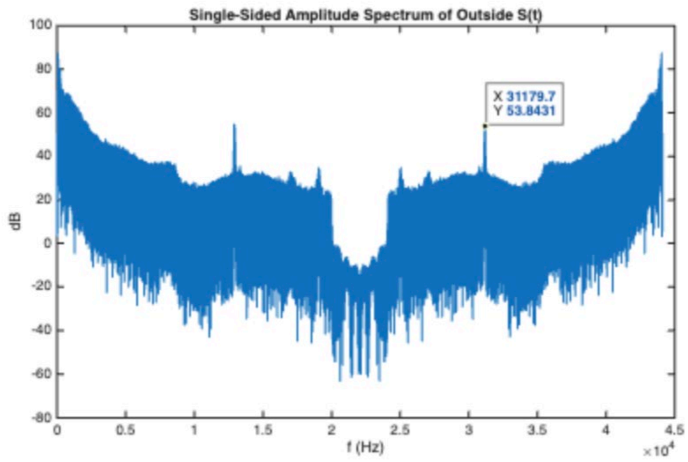


Figure 3

The Single-Sided Amplitude Spectrum (SSA) of the outside sound signal shows the distribution of acoustic energy across frequencies. The spectrum indicates that the dominant frequency components are concentrated at low frequencies below 10 kHz, with several noticeable peaks, such as the one around 31.18 kHz reaching approximately 54 dB. The overall trend shows higher energy at both very low and high frequencies, while mid-frequency components (around 20–25 kHz) have lower amplitudes.

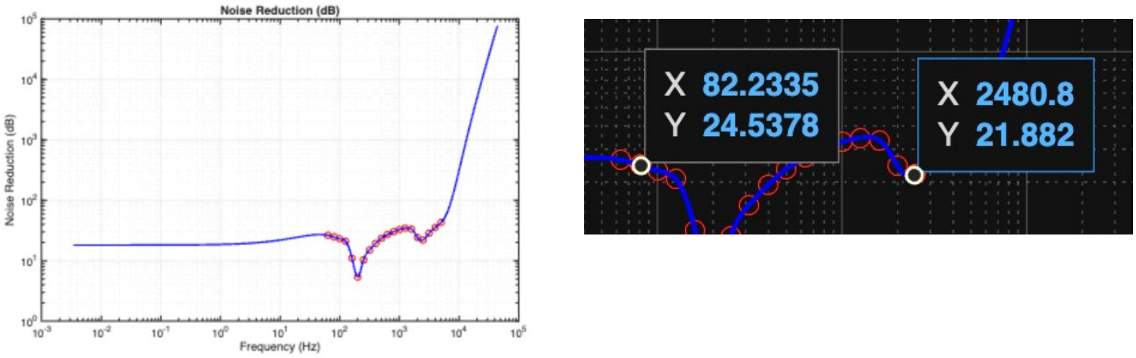


Figure 4

The figure shows the noise reduction between the outside and inside measurements as a function of frequency. For most of the frequency range, the noise reduction is around 20 dB, showing consistent sound attenuation. At some frequencies, the noise reduction drops to a minimum of about 13 dB, likely due to frequency dependent transmission effects. Overall, the results indicate effective noise reduction.

WP2: Signal Processing

Work package 2 are equipped with the task of signal processing. Its main objective is to analyze measured traffic-noise data by applying frequency-domain techniques, weighting functions, and benchmarking results against international noise guidelines (e.g., FTA).

WP2 methodology

WP2 addressed Objective 2 by processing and interpreting traffic-noise data from WP1 measurements and selected literature datasets using a consistent signal-processing workflow.

The work began with targeted review of environmental noise fundamentals and relevant international guidance to define the acoustic indicators to be computed. Noise recordings were then analysed in MATLAB (supported, where applicable, by the noise-meter software) to extract key time-domain metrics (e.g., LAeq, Lmax) and perform frequency-domain analysis (FFT-based spectra). Standard frequency weightings (notably A-weighting) were applied to support human-perception–relevant interpretation.

Processed results from measurements were benchmarked against literature values to identify trends and validate consistency, and then compared against guideline thresholds to classify existing noise levels and evaluate the effectiveness of mitigation measures (e.g., barriers and glazing). Finally, WP2 outputs (metrics, plots, and processed signals) were shared with WP3 to support integration into the web-based interface and contributed to interim/final reporting and dissemination.

WP2 Results and Discussion

Calibration

First to ensure both vibration devices are calibrated and provide the same data, we had both devices record at the same time at the same place and plot their waveforms on the time domain for the first 10 seconds:

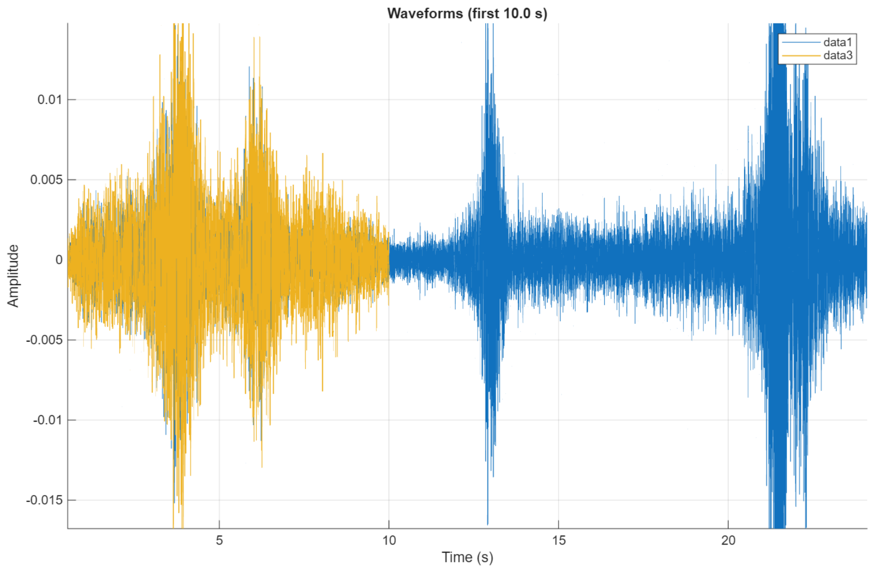


Figure 5: Vibration Devices Calibration

From the result we can notice that both devices produced almost identical curves so that insure that they are producing the same data.

Noise Reduction

In this experiment we will record two noise samples. Separated by a 1-inch double glazed window next to a busy street, we will have two microphones recording audio and two vibration measurement devices, as can be seen in Figure 6.

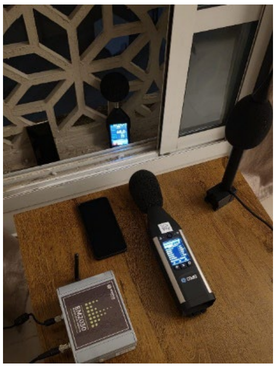


Figure 6

The first step in this experiment is to measure the noise reduction from the double glazed window and compare it with literature, The plot showing the difference between the inside and outside noise can be seen in Figure 7 below.

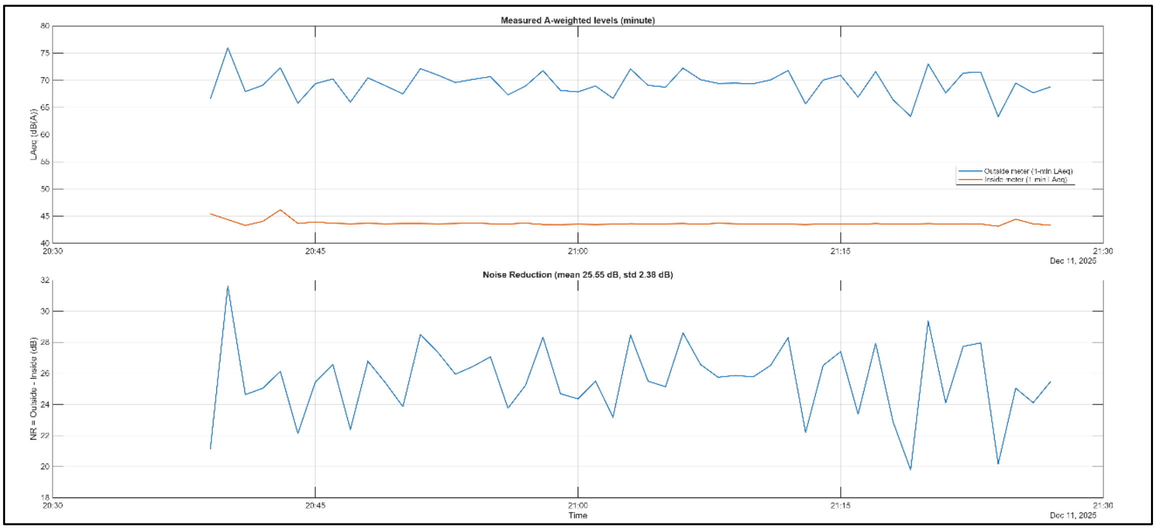


Figure 7

We can see that we have an approximate mean noise reduction of 25.65 dB with most minutes roughly in the 20.6 to 29.0 dB range. According to Locher et al. [8], Terzakis et al. [9], the dB(A) for closed windows range in the 25-30 dB range with sources narrowing it down to 25 – 28 dB range.

Applying Noise Reduction Metrics to Audio Recording

The aim is to use the noise reduction metrics we generated from the noise meters in order to estimate the sound that is produced inside of the house using the audio we recorded outside. And then comparing it with the actual noise inside the house. When we apply these noise metrics and plot the graphs in both the time domain and frequency domain we receive the following graphs:

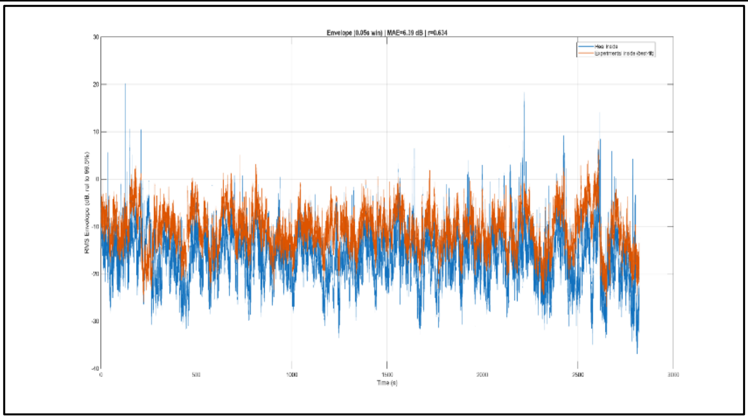


Figure 8: Comparison in the time domain

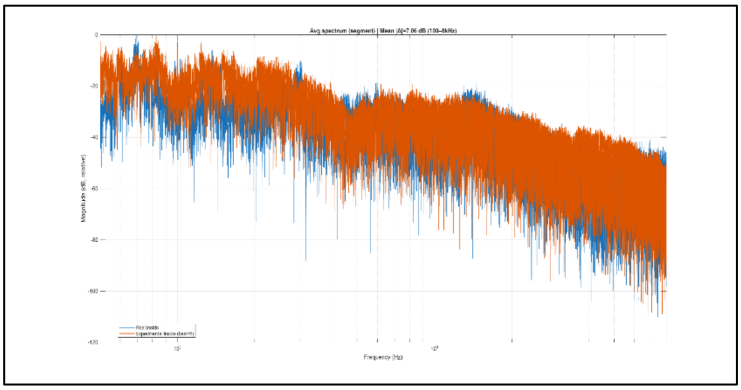


Figure 9: Comparison in the frequency domain

From these graphs we can see that the plots almost identically align with each other, confirming that we can estimate the true sound and reduction using only the audio we receive before applying the window.

WP3: Development of website and user interface

Work Package 3 developed the website: http://www.noise.qa/ which reads from https://sound-insulation-app-1071126322249.europe-west1.run.app/.

The work began with a focused review of environmental noise guidelines and established measurement practices. This review supported the layout of the website by clarifying which sound metrics are most relevant to typical use cases. We also examined examples of acoustic data presentation from literature and online sources to identify common structures that make information easier to interpret. Internal feedback at this stage helped refine the early design and ensured that the planned interface supported both technical accuracy and ease of navigation.

The development phase used FastAPI for the backend to provide a stable structure for routing, data handling, and communication with processing modules. Tailwind CSS was used to style the interface because it supports consistent and responsive layouts that scale across different devices. We added the ability for users to record audio through the Web Audio API. This allows the browser to access the microphone signal and extract a time-varying representation of the sound. Live visualizations show two key views of the signal: the waveform, which represents pressure variations over time, and the spectrogram, which represents energy across frequency bands. The interface also computes and displays sound pressure level estimates, allowing the user to observe level variations while recording.

Alongside these interface components, we developed a Python module named InsulationSimulator. This module processes uploaded audio and simulates the effect of insulation by operating in the frequency domain. The processing chain applies A-weighting to approximate human perception and uses insertion-loss curves for glazing. These curves represent how single or double glazing reduces sound at different frequencies. After applying these modifications, the module returns a reconstructed time-domain signal that the user can listen to. This approach helps relate frequency-dependent attenuation to heard differences, which is important because many users understand sound more effectively through listening than through inspecting values alone.

During development, we carried out iterative testing to confirm that the interface behaved consistently across recordings of different loudness and spectral content. We made adjustments to improve clarity, such as modifying color choices for graphs and adjusting scaling to avoid saturation when recording louder sounds. These changes followed feedback from team members and observations during development.

WP3 Results and Discussion

The results of WP3 show that the planned interface is feasible and functions as intended. The website now includes a landing page that introduces the aim of the project and explains why sound insulation matters in built environments. The platform also contains a milestones section that tracks the progress of each work package. These structural elements provide context for users and give a clear entry point into more detailed exploration.

The interactive features form the core outcome of WP3 to date. Users can record audio in real time, observe the waveform and spectrogram, and see how level metrics change as they speak, clap, or generate other sounds. These features turn the abstract idea of “sound level” into something observable. The changes in amplitude in the waveform and the spread of energy in the spectrogram give insights into how different sounds behave, including how higher frequencies appear as narrow energy bands and how lower frequencies spread more widely.

The insulation simulation feature is also functioning. The system accepts uploaded recordings, applies A-weighting and glazing insertion-loss curves, and generates a modified recording that represents how the original sound would change if insulation were present. Listening to the original and processed recordings shows that glazing tends to reduce higher frequencies more strongly, which aligns with known behavior of window systems. These differences may not always be obvious from looking at dB values alone, but become clear when users listen to before-and-after audio.

Taken together, these results indicate that WP3 meets its main aim of linking measured and processed data with auditory experience. The platform supports both visual analysis and perceptual interpretation. This dual approach has value because noise assessment often requires understanding how a numerical reduction translates into perceived change. WP3 provides a foundation for that kind of comparison.

Conclusion

This work successfully demonstrated an end-to-end signal-processing and validation pipeline for assessing road-traffic noise and evaluating mitigation effectiveness. Field measurements conducted across a 1-inch double-glazed window next to a busy street quantified the outdoor-to-indoor noise reduction. The measured reduction showed an approximate mean of 25.65 dB, with most minutes falling in the ~20.6–29.0 dB range, which aligns with reported closed-window outdoor–indoor attenuation ranges discussed in the supporting literature and guidance referenced in this report.

The project validated a practical approach for estimating indoor sound from an outdoor recording by applying the measured noise-reduction metrics to the outside audio signal. The resulting experimental “inside” signal produced strong agreement with the actual indoor recording, particularly in the frequency domain, supporting the conclusion that the measured reduction metrics can be used to approximate indoor acoustic conditions from outdoor measurements alone.

The work has produced a functioning platform http://www.noise.qa that enables users to explore environmental noise through recorded audio, visual representations, and simulated insulation effects. The website now combines measurement results, processed data, and perceptual listening features in a format that supports clearer understanding of how insulation influences sound levels.

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[9] Terzakis, M. E., Naim, F., Van Hoorickx, C., Hornikx, M., Fecht, D., Hansell, A. L., & Gulliver, J. (2025, April 21). *Estimation of outdoor-to-indoor noise attenuation for night-time residential noise exposure based on noise indicators* (SSRN Working Paper, 42 pp.). SSRN. (SSRN)

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