# Sound Quality Improvement using Low Weight Reinforced Thermoplastics (LWRT) in Automotive Air Conditioning Systems

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## Introduction

The usage of Low Weight Reinforced Thermoplastics (LWRT) [1] in automotive applications promises to reduce noise immission in the vehicle interior as well as to reduce weight. This reduction of noise is discussed using the example of the air conditioning system.

These differences in sound were assessed using algorithmic evaluations as well as subjective listening tests. For the listening tests, both psychoacoustic loudness and annoyance were rated, with loudness having been shown previously to offer a good predictor for annoyance as assessed in the laboratory. The main criterion evaluated algorithmically was the predicted loudness after DIN 45631/A1 [2].

## Assembly

The precise assembly under investigation is the climate control system for the front seats in an Audi A8 luxury sedan. This system consists of the actual air conditioning unit, itself comprising the air intake unit and the air distribution unit; and of the air ducts, which can be separated into the shorter middle ducts, which lead to the air vents above the center console, and the side ducts, which take the longer path from the AC unit to the side vents, near the driver and passenger windows, respectively.

These four components (intake, distributor, middle vent, side vent) in their stock form were individually replaced by components made from an LWRT manufactured by Röchling Automotive AG called Seeberlite; and various combinations of stock and LWRT components were fitted to the vehicle and measured in a parked and shut vehicle with the engine off using a dummy head microphone system.

Two modified states representing reasonable choices for varying degrees of practical modifications and the stock system were chosen to evaluate specifically in this paper. An overview of their material configurations as well as the names used to refer to them henceforth can be seen in Table 1.

**Table 1:** Climate System Configurations

| Component | Configuration Name | | |
|---|---|---|---|
| | **Stock** | **Mid Vent** | **LWRT** |
| Intake unit | Stock | Stock | LWRT |
| Distributor | Stock | Stock | LWRT |
| Middle vent | Stock | LWRT | LWRT |
| Side vent | Stock | Stock | LWRT |

The air conditioner was measured at two air flow rates—4 kg/min and 8 kg/min. As these measurements were made in a standing car with the engine off, they are most representative of a vehicle standing in traffic or at a red light, particularly one with a hybrid or electric drivetrain or with combustion engines using start-stop systems.

Additionally, recordings were made on a test track, with the vehicle driving on a smooth surface at 50 km/h as a representative speed for city traffic. These measurements were combined with the air conditioner measurements in order to estimate the audibility of the climate system in a moving vehicle.

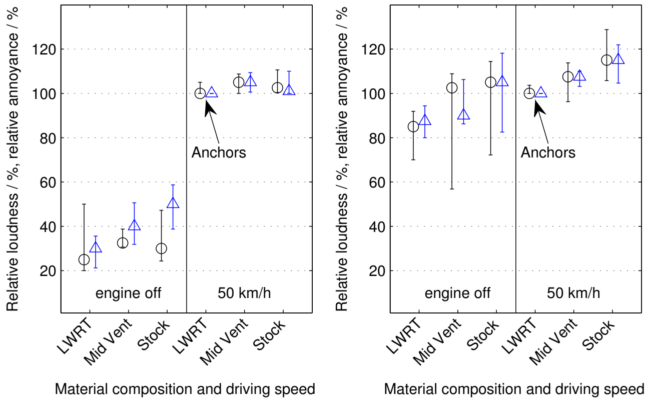
In total, 12 different sounds were evaluated (2 driving speeds, 2 flow rates, 3 material configurations).

Subjective tests were performed using the Magnitude Estimation method, as described by Fastl and Zwicker[3]. Test participants were presented with a 1 sec sample of an anchor sound followed by a 1 sec sample of randomly selected sound out of the pool of sounds to be evaluated, separated by a 0.5 sec gap. The anchor was assigned a numerical value of 100 and the participants were asked to rate a quality (loudness, annoyance) of the second, variable sound scaled relative to that.

The sounds were presented via a level-calibrated STAX headphone system in a quiet environment. Each sound was judged four times in total by each person, and the considered evaluations were preceded by 8 discarded training sounds in each listening session to allow the test subjects to get a feeling for what levels of sounds were to be expected. The tests were performed on 1 female and 6 male subjects between the age of 18 and 49, with a median age of 32.

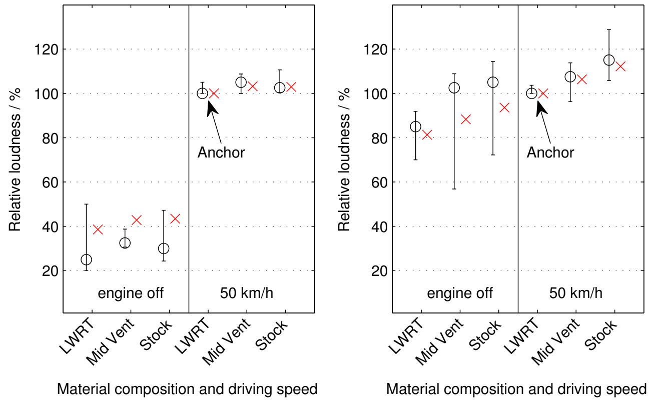
These results are shown as intra-individual median values, each derived from 28 data points, with the intra-individual interquartile ranges of these medians shown as error bars.

Instrumental evaluation of the sound recordings was performed using the Müller-BBM VAS software PAK, which offers an analysis of the instationary loudness of sound recordings. The $N_5$ percentile loudness after DIN 45631/A1 was calculated from these values and is displayed as a value relative to that of the respective anchor sounds in the diagrams of this paper.




**(a)** 4 kg/min air flow **(b)** 8 kg/min air flow

**Figure 1:** Subjective relative loudness (circles) and annoyance (triangles). Values given relative to the respective anchor.




**(a)** 4 kg/min air flow **(b)** 8 kg/min air flow

**Figure 2:** Subjective relative loudness (circles) and instrumentally predicted $N_5$ loudness (crosses). Values given relative to the anchor.

# Results

The results for the psychoacoustic evaluation are shown in Figure 1, with both loudness and annoyance visible for each sound. Both characteristics were determined using two separate listening tests with their own unique sets of sounds, grouped together by flow rate and shown as separate subfigures. Thus it is not possible to directly compare the results from the two flow rates with each other, as they are scaled relative to different anchors.

It can be seen that the results for loudness correspond very closely to the results for annoyance, a relation that has been shown previously [5]. One noticeable exception to this correspondence is the stock climate system being rated at standstill as more annoying than it is loud. Instrumental analysis suggests that the difference in loudness between the Mid Vent system and the Stock system is small, so that this divergence may well be accountable to the subtleties in the differences between the sounds. Improvements when moving towards more LWRT in the system can be seen within the individual group of sounds for both loudness and annoyance, with the maximum improvement visible for the annoyance in a standing vehicle. However, for 50 km/h with the low air flow rate of 4 kg/min the improvements become marginal.

In order to assess the possibility of avoiding time consuming listening tests in the future, the accuracy of DIN 45631/A1 for these sounds was also considered. Figure 2 shows the results from the subjective loudness tests next to the calculated $N_5$ percentile loudness. It is clearly visible that these two results are quite similar, i.e. usually instrumental values (crosses) are within the inter-quartiles of subjective evaluations. This result was to be expected based on previous findings [4].

# Discussion

The results of the listening tests and measurements go to confirm the assumptions that LWRT offers a reduction in noise output for automotive and climate applications. Specifically psychoacoustic annoyance is reduced by up to 40 % in the best case situation of a fully LWRT climate system in a standing vehicle for a moderately low air flow. However, even just replacing the middle air vent duct with LWRT material reduces loudness and annoyance by between 5 and 15 % for many inner city driving conditions.

Additionally, loudness according to Zwicker from DIN 45631/A1 is shown to offer a suitable method of quickly estimating the total perceived annoyance of passengers with a good degree of accuracy.

Further research remains to be done concerning the perceived sharpness reductions using LWRT, as instrumental values show noticeable improvements in sharpness for the sounds evaluated here.

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