Room Acoustics Model Calibration: A Case Study With Measurements

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1 Introduction

Poor classroom acoustics can result in low levels of speech intelligibility, cause stress for both teachers and students, and detract from the overall education experience. While typical classroom finishes like acoustical ceiling tile and wall panels provide a means of absorbing sound, these are less suitable in speciality classrooms like construction workshops, specialized laboratories, and culinary arts teaching kitchens.

Due to complaints of poor speech intelligibility in a wine-tasting classroom built with kitchen finishes, an acoustical investigation was conducted. This paper presents the methods used to assess the acoustical performance both before and after installation of retrofit acoustical materials that did not significantly alter the visual aesthetics of the classroom as was required.

2 Method

As part of the assessment, measurements and room acoustics modelling was performed using Odeon ray-tracing acoustical software both before and after retrofit construction.

2.1 Initial visit

During an initial visit, the classroom was observed to be constructed from hard-tiled and stone walls, exterior and extensive interior glazing, epoxy concrete floors, and a gypsum board ceiling (see Fig. 1).

2.2 Pre-retrofit modelling and measurements

To assess the acoustical conditions of the original classroom, impulse response measurements were performed at several locations using the swept-sine approach as built into Odeon. A Trimble SketchUp model of the room was created by AcoustiGuard to define its geometry, which was then imported into Odeon. Based on visual observations of room finishes, estimates for absorption coefficients were assigned in Odeon to the room's surfaces using the built-in material database.

A comparison of the predicted and measured room acoustical parameters was made for each measurement location. To improve the accuracy of the model, it was calibrated to the measurements using the Genetic Algorithm (GA) built into Odeon. This procedure allows the user to define a potential range in octave bands for each material's absorption coefficients. The GA iteratively changes the material properties and recalculates the model until a better match with the measured parameters is achieved. The GA is essentially a search algorithm that works well with multi-dimensional problems and converges to the most optimum solution [1].

2.3 Retrofit design and construction

Based on the calibrated Odeon model, specific retrofit acoustical materials were evaluated based on manufacturer's absorption data. To preserve the aesthetics of the room, material selections were specifically limited to (1) options without exposed fibres, and (2) transparency, such as transparent Micro-Slotted Panels (MSP) [2] and Perforated Gypsum Board (PGB) ceilings with fibre backing [3].

The MSP were installed to partially cover the windows, wall tiles, and interior glazed walls while the ceiling was entirely converted to PGB with 2" of mineral fibre above only the perimeter of the ceiling. The look of the room was essentially maintained after the retrofit installation, as can be seen by comparison between Fig. 1 and Fig. 2.

Figure 1: Original classroom

Figure 2: Retrofit classroom

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2.4 Post-retrofit modelling and measurements

Once the retrofit materials were installed, additional acoustical measurements were performed following the same procedure as the initial measurements.

For the retrofit model, a comparison of the predicted and measured room acoustical parameters was made. The GA was again used to calibrate the room acoustics model to the measurements.

3 Results

The average reverberation time (T20) measurement (of 15 measurement points and two source positions) and the prediction results for the original and retrofit room, both before and after calibration, are plotted in the figures below.

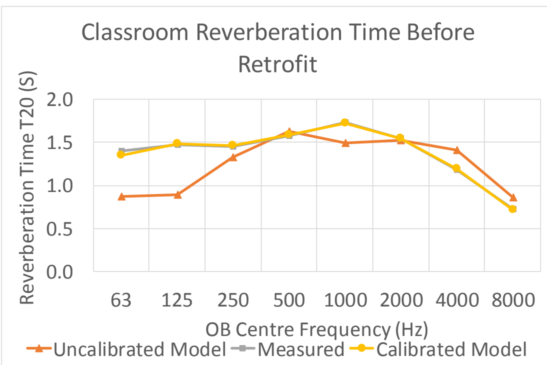

Figure 3: Pre-retrofit results

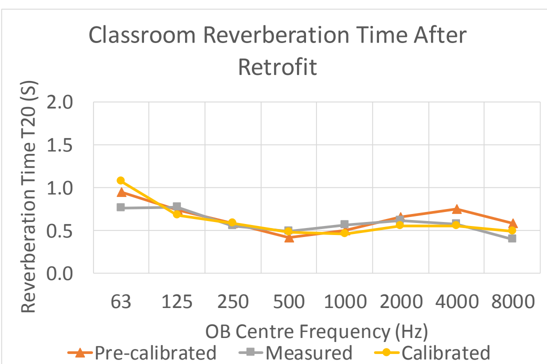

Figure 4: Post-retrofit results

4 Discussion

The results show that the retrofit materials significantly reduced the mid-frequency reverberation time within the classroom from an average 1.6 s to 0.6 s. This reduction also resulted in a substantive improvement in speech intelligibility from STIPA 0.44 "Poor" to 0.64 "Fair".

From Figure 3, for the pre-retrofit case, the reverberation time of the initial un-calibrated model had significant error in the 63 Hz and 125 Hz bands and noticeable error between 250 Hz and 8000 Hz. However, after calibration, the modelled reverberation time almost exactly matches the measured reverberation time with no noticeable error. This result should be expected since the initial un-calibrated model was based entirely on estimates of surface absorption coefficients. It is surprising that the un-calibrated results are mostly lower than the calibrated results since it is known that current methods of evaluating material absorption typically under-estimate actual absorption. This could be due to inaccurate assumptions about the cavities behind the existing surfaces. At higher frequencies, the expected trend was observed. It is encouraging that after calibration the results match the measurements indicating that the calibration is a worthwhile procedure.

From Figure 4, for the post-retrofit case, the calibration was seen to have less of an effect since the base model was already calibrated. This also suggests that the material properties provided by the material suppliers were reasonably accurate except at the highest frequencies where actual absorption was slightly higher as expected. There was some noticeable remaining error at 63 Hz likely caused by constraints placed upon the GA during the calibration process that prevented it from adjusting material absorption coefficients outside of a defined range.

5 Conclusion

A classroom with poor acoustics and low levels of speech intelligibility was studied as part of installing retrofit acoustical materials. Based on initial in-situ material guesses and impulse response measurements, a room acoustics model was created and calibrated using Odeon ray-tracing acoustical prediction software and its built-in Genetic Algorithm. The calibration significantly reduced prediction error of the pre-retrofit model compared to measurements. This is because all the material properties of the pre-retrofit model were estimated by matching materials from the Odeon database based on visual observations in the room. The post-retrofit model still benefited from calibration, but since it was based on the calibrated pre-retrofit model most of the material properties were already calibrated. Without a calibrated pre-retrofit model, it should be expected that there would have been larger errors in the post-retrofit prediction. This demonstrates that calibration of ray-tracing models is a worthwhile exercise when accurate predictions are required for selecting retrofit materials. Without calibration, there may be noticeable error in the prediction results.

Acknowledgments

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References

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[2] DeAmp Panels: https://goo.gl/3vviTP

[3] Knauf Danoline Perforated Drywall: https://goo.gl/eF1Fpp