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INVESTIGATING HOW PREDICTIONS OF REVERBERATION TIME CAN BE AFFECTED BY INCORRECT ABSORPTION COEFFICIENT ASSUMPTIONS

Lawrence Yule

Southampton Solent University, School of Media Arts and Technology, Southampton, UK.

Benjamin Ford

Southampton Solent University, School of Media Arts and Technology, Southampton, UK.

The methods of predicting reverberation time for any given space rely on the correct choice of absorption coefficients for the room's surfaces. For many materials the absorption coefficient can be found in literature, taken from measurements carried out using an impedance tube or a reverberation chamber. For other materials finding the absorption coefficient may not be possible, either because the material has not been measured before, or because the construction of the material is different from that found in literature. In this scenario an acoustic consultant will have to choose the closest material they can find, based on what it's made of, its thickness, its construction, and its positioning. This introduces a degree of error to the acoustic modelling process which may have an impact on the predicted reverberation time, as well as subsequent predictions such as speech intelligibility. This paper examines the variance in reverberation time predictions caused by the use of incorrect absorption coefficients, and compares the results to measurements taken in accordance with ISO 3382-2:2008. This paper also investigates if the use of an acoustic impedance "gun" (by Microflown) is suitable for use in measuring the in-situ absorption coefficients of every surface of a room, to be used in the prediction of reverberation time using acoustic modelling software. If the acoustic impedance of materials can be measured in-situ the calculated absorption coefficient is likely to be more suitable for use in determining the reverberation time of the space, as opposed to using assumed values of absorption taken from literature.

1. Introduction

In order to acoustically model a room for use in predicting reverberation time the absorption coefficients of the room's surfaces must be known. In the large majority of cases these coefficients cannot be directly measured, and so the most appropriate coefficient is chosen from literature. For many common materials that are not manufacturer branded or tested, it is an educated guess as to which coefficient is most appropriate, or which source is best to use. This study investigates the level of variance that can found for a common classroom, by identifying a large range of sources for absorption coefficients and comparing them. The level of variance found for the same material has been evaluated, followed by using acoustical modelling software to predict the reverberation time of the room (RT60). The room's RT60 has been measured in accordance with ISO 3382-2:2008, for comparison with the predicted results. An acoustic impedance "gun" (by Microflown) has also been used to directly measure the absorption coefficients of the classroom's surfaces, to evaluate its effectiveness against current methods.

"One of the main problems in modelling real halls is the difficulty to obtain accurate material characteristics, because absorption data are unknown for most of the materials. Therefore, typical absorption coefficients were considered in this study." (Cammarata et al., 2001).

2. Method

2.1 The Test Room

The classrooms measures 10.83m x 8.11m x 2.41m. Total volume 211.7m^3. The floor is covered in thin carpet tiles on concrete, while the ceiling is made up of suspended tiles with a cavity above. The double doors are 50mm thick wood panels with small glass windows. The walls are made up of either plasterboard or painted brick. White boards cover the majority of the front wall of the room, mounted on the plasterboard wall. 25mm thick fabric covered panels cover areas of the other 3 walls, along with wooden slatted radiator covers (10cm spacing from the wall, 2cm air gap between 5cm slats). Two windows can be found at the back of the room, made up of 1.2m x 1m double glazed glass. Nine large circular tables (r=0.75m) were evenly spaced around the room in rows of 3. The following table shows the combined surface areas of the 8 different materials in the room:

Table 1: Room surface areas

Surface	Surface Area (m^2)	Percentage area (%)
Carpet	87.83	32.90
Ceiling	87.83	32.90
Plasterboard	27.63	10.35
Wooden radiator cover	22.66	8.49
Brick Wall	18.84	7.06
Absorptive Panel	16.17	6.06
Door	3.33	1.25
Window	2.66	1.00
Total	**266.95**	**100**

Figure 1: The classroom

2.1.1 Measurement of Reverberation Time

Measurements were taken using a Brüel & Kjær Type 4292-L omni-directional loudspeaker as a source, driven by a Norsonic Nor280 amplifier. The built-in signal generator was used to produce pink noise, triggered via a remote control. An NTi XL2 sound level meter was used to measure RT60 (T30). Two source locations were used, with 24 receiver positions. Results are given in 1/1 octave bands, from 125 Hz to 4 kHz. Results (4.3) have been arithmetically mean averaged per band, along with standard deviation (+/-).

2.1.2 Acoustical Modelling

Modelling of the room has been carried out using CATT Acoustic, a room acoustics prediction and auralisation package. The model has been used to predict the reverberation time (RT60) of the room based on a range of commonly used absorption coefficients, as well as those measured in-situ using a Microflown impedance "gun". The white boards and "smart" board found on the front wall of the room have been omitted, as they are likely to be highly reflective materials for which data won't be available in literature. The tables have also been omitted, again because they are likely to be highly reflective without any reference data available. This also helps to simplify the model. Ray tracing was chosen over the Eyring and Sabine models for the calculation of reverberation time, to provide the most accurate prediction. Absorption coefficients have been used in the frequency range of 125 Hz – 4 kHz in 1/1 octave bands.

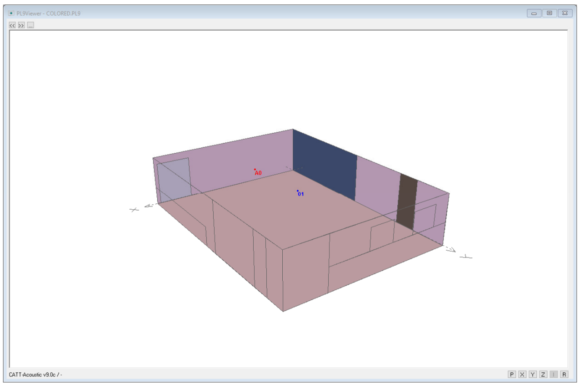


Figure 2: CATT Acoustic Model

2.1.3 Choice of Absorption Coefficients

For this particular room there are 8 different materials; A painted brick wall, wooden slatted radiator covers, fabric covered absorptive wall panels, ceiling tiles (with air cavity), painted plasterboard, wooden doors, double glazed glass windows, and carpet tiles on concrete. Of these materials, none are manufacturer branded, and the appropriate absorption coefficients have been taken from common literature. There are a wide range of sources for absorption coefficients, as well as ambiguity as to which will be the most appropriate to the materials in question. Added difficulty is incurred when, for example, a ceiling tile has a cavity above it of unknown size, potentially with absorptive material present. For more bespoke materials such as the wooden slatted radiator covers it may be impossible to find an appropriate absorption coefficient, and the next closest alternative will have to be used.

A web based search has been carried out to identify the most common sources available online, as well as a selection of books on room acoustic and room design that contain lists of absorption coefficients for common materials and surfaces. Many of the web sources identified did not provide any information as to how they were measured, or where they have been sourced from, whereas all of the book sources found did at least provide sources for where they were compiled from. A total of 18 different sources were used, providing a total of 114 coefficients across the 8 materials. A number of duplicates have been removed to leave a total of 78 coefficients. The number of coefficients found for each material is shown in Table 2:

Table 2: Absorption Coefficient Sources

Material	**Total**	**After Duplicates removed**
Brick Wall	10	3
Carpet	21	13
Window	14	7
Absorptive Panel	11	10
Plasterboard	29	19
Ceiling Tiles	15	15
Doors	8	5
Wood Panelling	6	6
Total	**114**	**78**

Due to the large number of coefficients found in literature it is difficult to compare them all in a meaningful way. The chosen method of determining the level of variance in calculated RT60 in this case is to take the extremes of the coefficients, the very lowest and very highest coefficient for each material and compute those in the model. An average range of coefficients for each material has also be used to compare with the measured RT60.

2.1.4 Measurements of in-situ absorption

Measurements were taken for each of the room's surfaces using a Microflown in-situ impedance "gun". Three measurements were carried out per material, moving to a different area each time to allow for natural variation, which has subsequently been averaged. The absorption coefficients have been measured in 1/1 octave bands from 125Hz-8kHz, which matches the recommended frequency range of the system (300Hz-10kHz) minus the lowest frequency bands of 125Hz and 250Hz. The 125Hz and 250Hz bands have been included regardless, as results are given down to the 160Hz 1/3 octave band. This measurement range corresponds to the input range of the chosen acoustic modelling software, CATT Acoustic. The "Q-Term" impedance model was used for all measurements as it is considered by Microflown to be the most accurate method (refer to the Microflown in-situ manual for more information). Based on manufacturer recommendation the system is only applicable for use on samples of at least 30cm x 30xm in size. For almost all of the surfaces measured this is easily achieved, however the wooden radiator covers have large spacing's in between their thin slats.

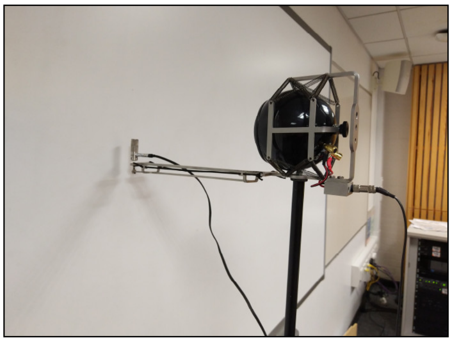
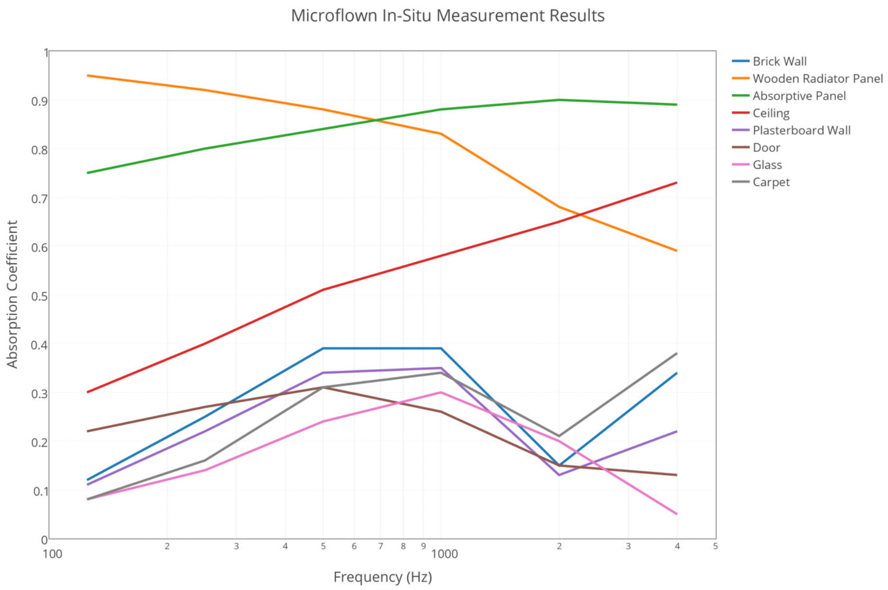


Figure 3: Microflown in-situ measurement system

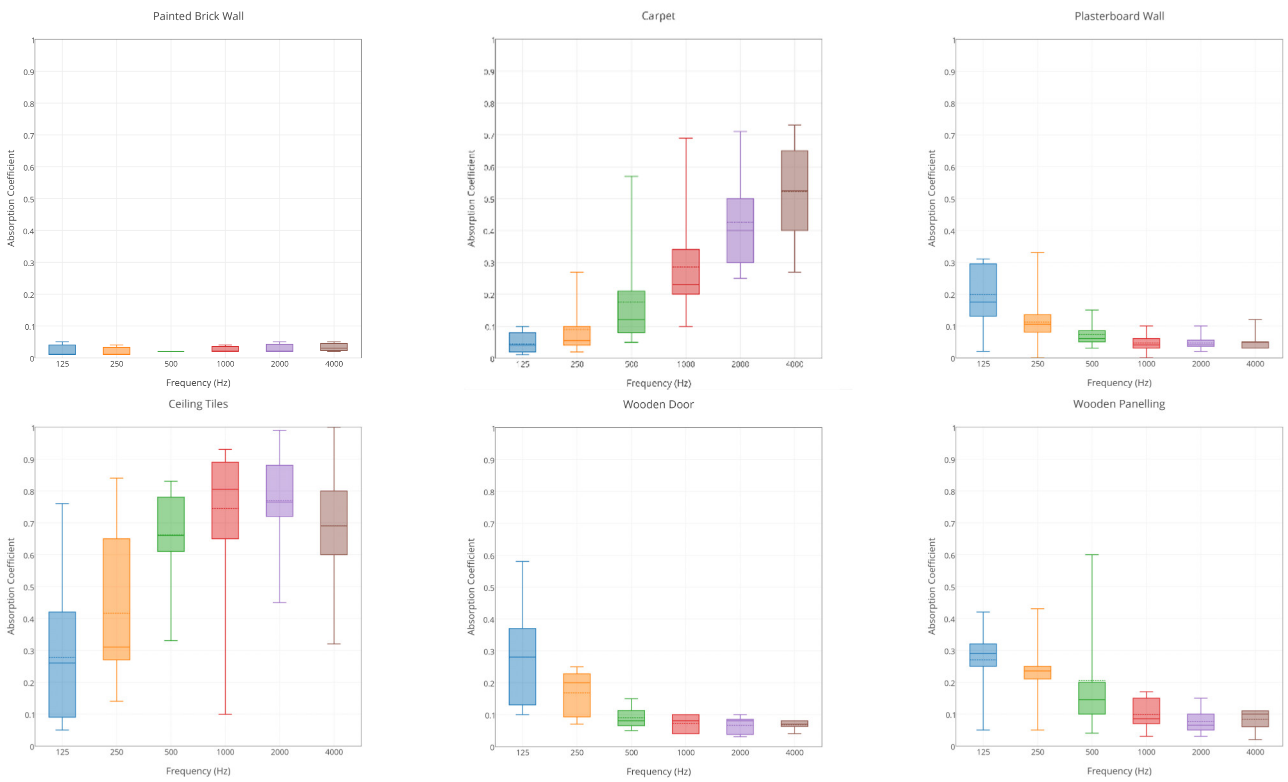
3. Results

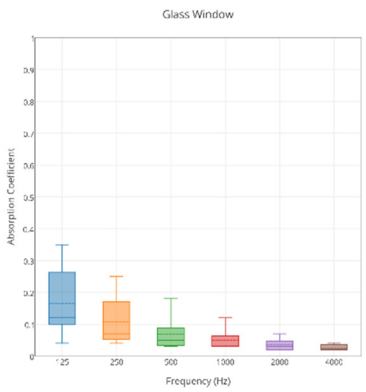
3.1 Measurements taken using in-situ Microflown system

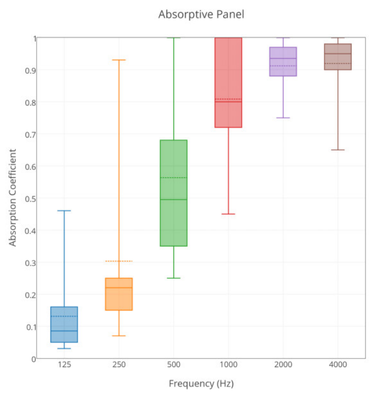
Results are shown as an average of the 3 measurements taken for each material. Standard deviation was calculated to be less than +/-0.1 for all materials.



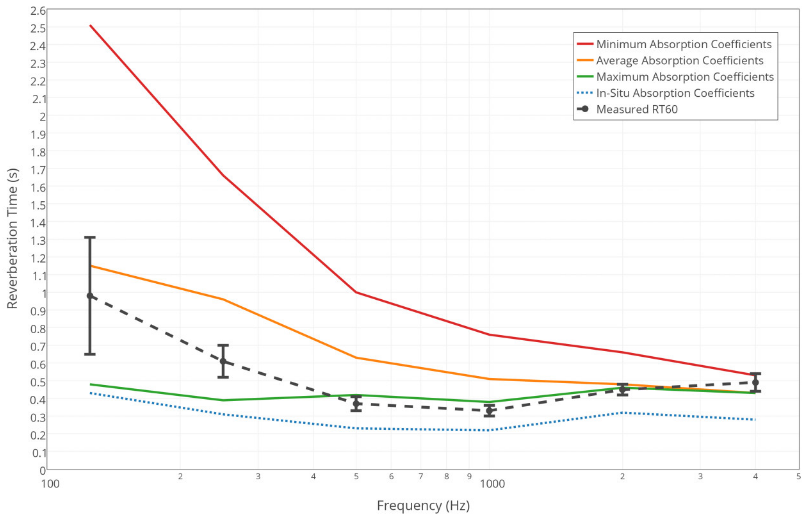
3.2 Comparison of absorption coefficient variance for each material







3.3 Comparison of calculated RT60 values using highest, lowest, and average absorption coefficients for each material vs measured result and in-situ method



4. Analysis

Box and whisker plots (4.2) show the range of data points for each frequency, the interquartile range, the median (solid line) and the mean (dotted line), with the difference between the two indicating the skew of the data. The largest variations in absorption coefficients are found in the carpet, absorptive panelling, and ceiling tiles. The door, windows, plasterboard wall, and wooden panelling show a small range with greater variation at low frequencies. The absorption coefficients found for painted brick walls are all within 0.02 of each other, and highly reflective.

Analysing measurements taken in-situ (4.1) the more reflective materials (the door, plasterboard, glass, brick wall, and carpet) all have a very similar absorption coefficient across the frequency range, while being substantially more absorptive than the results found in literature (especially in the 500 Hz – 1 kHz range). The result for the wooden radiator covers is unexpectedly high, likely due to the slats and gaps which don't allow for the suggested sample size of 30cm x 30cm. The generally higher absorption coefficient values than found in literature have contributed to the final RT60 result being lower than the predicted results (4.3), but the curve fits well with the measured result, falling between 0.11s (at 1 kHz) and 0.55s (at 125Hz) below the mean.

Results for predicted RT60 (4.3) show a large variance in predicted reverberation time with the range of found absorption coefficients. The difference between the lowest and highest absorption coefficient values is a range of 2.0s at 125 Hz, reducing to 0.6s at 500 Hz, and further reducing to 0.2s at 4 kHz. The measured level of the room fits closely with the predicted RT60 using the highest level of absorption coefficients, especially above 500 Hz (within 0.1s). This indicates that for one or more the materials in the room a higher level of absorption should have been chosen from literature, potentially the wooden slatted radiator cover that proved difficult to choose an appropriate absorption coefficient for.

The most varied material from literature was the absorptive fabric covered panelling, as there is a huge range of possible materials that it could be comprised of, not to mention the variance in thickness and construction. In this room the panels cover 10% of the room's surface, which paired with the potentially high absorption coefficient, has a large effect on the predicted reverberation time. Based on measurements taken with in-situ setup the panel has a substantially higher level of absorption than the selection identified in literature, especially <1000 Hz.

5. Conclusions

For even a relatively small room such as this classroom the range of absorption coefficients used in this study contributed to a large variance in predicted RT60. It is expected that for a larger room the choice of absorption coefficient would have an even greater effect on RT60, and would dramatically affect the prediction of metrics such as speech intelligibility. For any room careful attention should be paid to the materials that cover the largest surface area, as they will have the greatest impact on the reverberation time. In this classroom the ceiling and floor cover the largest area, a total of 66% of the room (33% each), while also being two of the most varied materials found in literature (4.2). Many of the more reflective materials (the brick wall, plasterboard, glass window, wooden door) all had very similar coefficients across sources, indicating that it is much more important to focus on selecting the appropriate coefficients for the more obviously absorptive materials, which have a greater range of coefficients available to choose from.

It has been shown that the Microflown in-situ measurement setup is applicable for acquiring absorption coefficients for use in acoustical modelling, as the predicted result is close to the measured value, however the configuration/settings used in this study returned a higher level of absorption per material than is indicated by the literature. This could be partly attributed to the construction and backing of the materials measured in-situ, and also the systems apparent limitations measuring particularly reflective materials. It should be noted that for materials that do not meet the minimum size criteria or that are oddly shaped/constructed an absorption coefficient may still be sourced from literature.

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