Development of a small-scale reverberation room

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ABSTRACT

A reverberation room was desired on-site in order to measure the absorption coefficients of materials during the research and development process without utilising external laboratories. Making use of the available resources, a regular office was converted into a small-scale reverberation room. Whilst an ideal reverberation room has a volume of at least 200 m^3, this reverberation room was designed around the limited 48 m^3 room volume. Significant construction work was conducted to convert the room, including the implementation of diffusion panels. Verification of the room was carried out by testing in conformance with ISO 354:2003 (with deviation to account for the room volume) using Reapor®, which has been tested in four different full-scale reverberation rooms to the same ISO 354:2003 standard, allowing comparisons to be drawn. Testing revealed satisfactory correlation between the small-scale and full-scale reverberation rooms. A small-scale reverberation room was successfully developed, saving time and resources by enabling us to test the sound absorption coefficients of materials during the research and development process, before sending the final material to an independent acoustical laboratory for accredited ISO 354:2003 results.

1. INTRODUCTION

Reverberation rooms can be used for a variety of acoustical testing, such as measuring the sound power of a source, the transmission loss of a structure, calibration of transducers, or the focus of this reverberation room: the sound absorption of a material. By definition, a reverberation room has a uniform distribution of sound energy, known as a diffuse sound field, where sound intensity is independent of location. A diffuse sound field means that sound energy can interact with a sample at all angles of incidence, which is effectively random incidence. An ideal reverberation room achieves this with non-parallel high density reflective surfaces, large room volumes of at least 200 m^3, omnidirectional sound sources and diffusive elements which may be stationary or moving.

The purpose of the test method is to measure the sound absorption of materials, evaluating how efficient a material is at absorbing sound energy. As the sound absorbing characteristics of a material is dependent on the angle of incidence, the diffuse sound field within the reverberation room allows measurement of the average sound absorption coefficients over all angles of incidences. This is in contrast to impedance tube testing, where the angle of incidence (0°) is singular (ASTM International, 2012). Whilst there are applications where normal incidence absorption coefficients are useful, random incidence absorption coefficients are typically more relevant.

This paper aims to explore the development of a reverberation room used for measuring sound absorption coefficients with a volume of 48 m^3, which is only 24% of the recommended 200 m^3 room volume specified in the ISO 354:2003 (International Organization for Standardization, 2003) and ASTM C423-09a (ASTM International, 2009) standards. The purpose of the room is to evaluate the sound absorption of materials during the research and development process without using an external independent laboratory, saving both time and cost.

2. CONSTRUCTION

The opportunity for a reverberation room conversion was conceived when an office adjacent to the research & development laboratory became vacant. It was rectangular shaped, 4.8 m long, 3.6 m wide and 2.8 m high, resulting in a room volume of 48 m^3. The floor consisted of a standard 150 mm thick steel-reinforced concrete slab with carpet glued onto it. The walls were single brick with penetrations for two windows and an air-conditioning unit. The ceiling was constructed using standard 10 mm thick plasterboard, with approximately 500 mm of space above between the ceiling and roof. A single light-weight hollow-core door with no seals was the only entrance/exit.

A brief analysis of the original room revealed a low reverberation time primarily caused by the lightweight construction of the ceiling and the absorptive carpeted floor. Furthermore, the poor transmission loss of the ceiling and door allowed outside noise events to interfere. Although the regular shape of the room and the limited 48 m^3 volume were noted issues, it was not possible to improve either issue without significant time or cost.

2.1 Ceiling

The ceiling was torn down and extensive upgrades were carried out to reinforce the ceiling timber structure in order to support the increased load. To replace the standard 10 mm plasterboard, three layers of 9 mm thick compressed fibre cement sheets were mounted in an overlapping fashion. The top layer was coated with a thick layer of damping compound. Lighting was not reinstated on the ceiling.


Photograph 1 and 2: Construction of the reverberation room ceiling

2.2 Doors and Floor

The single light-weight hollow-core door was replaced with two sealed hardwood solid-core doors. The carpet and adhesive were removed to reveal the bare concrete slab.

2.3 Walls

The air-conditioning unit and both windows were removed, and the remaining cavities were filled with bricks. Two PVC pipes, which were for ventilation to the spaces below the reverberation room, were wrapped with Soundlag™ 4525C and boxed with 9 mm thick compressed fibre cement sheeting. All electrical (except for one) and data points were removed from the walls, and any remaining gaps were sealed with the exception of a single penetration for microphone and speaker cabling. A single small LED floodlight was installed on the wall to provide lighting, with the switch located outside the room. Finally, the walls were painted to seal the surface.

2.4 Diffusion

Stationary diffusion panels of various sizes were hung from the ceiling at a variety of heights and angles, distributed evenly throughout the reverberation room. The Soundalloy™ MPM 2100 panels are constructed using two layers of aluminum bonded together with an adhesive damping layer, creating constrained-layer damped diffusion panels. In conformance with the recommendations given in the ISO 354:2003 and ASTM C423-09a standards, enough panels were hung for the area (both sides) of the diffusers to equal approximately 25% of the total surface area of the reverberation room and have a surface density greater than 5 kg/m^2. The diffusion panels were hung using snap hooks to allow for easy removal or adjustment during the diffusivity checks.


Photograph 3 and 4: Before and during the installation of the stationary diffusion panels

3. EXPLORATION OF REVERBERATION ROOM PERFORMANCE

3.1 Volume and Shape

ISO 354:2003 states a minimum room volume of 150 m^3, and ASTM C423-09a states a minimum room volume of 125 m^3. Both standards recommend at least 200 m^3, with a maximum room volume of 500 m^3 specified in ISO 354:2003, further reinforcing the small-scale aspect of the 48 m^3 Pyrotek reverberation room.

The room conforms to the shape condition specified within section 6.1.2 of ISO 354:2003:

$$I_{max} < 1.9\, V^{\frac{1}{3}} \tag{1}$$

Where I_{max} is the length of the longest straight line within the boundary of the room (6.6 m), and V is the volume of the room (48 m^3). The room also meets the shape conditions described within section 7.3 of ASTM C423-09a, where no two room dimensions are equal and the ratio of the largest to the smallest dimension is not greater than 2:1.

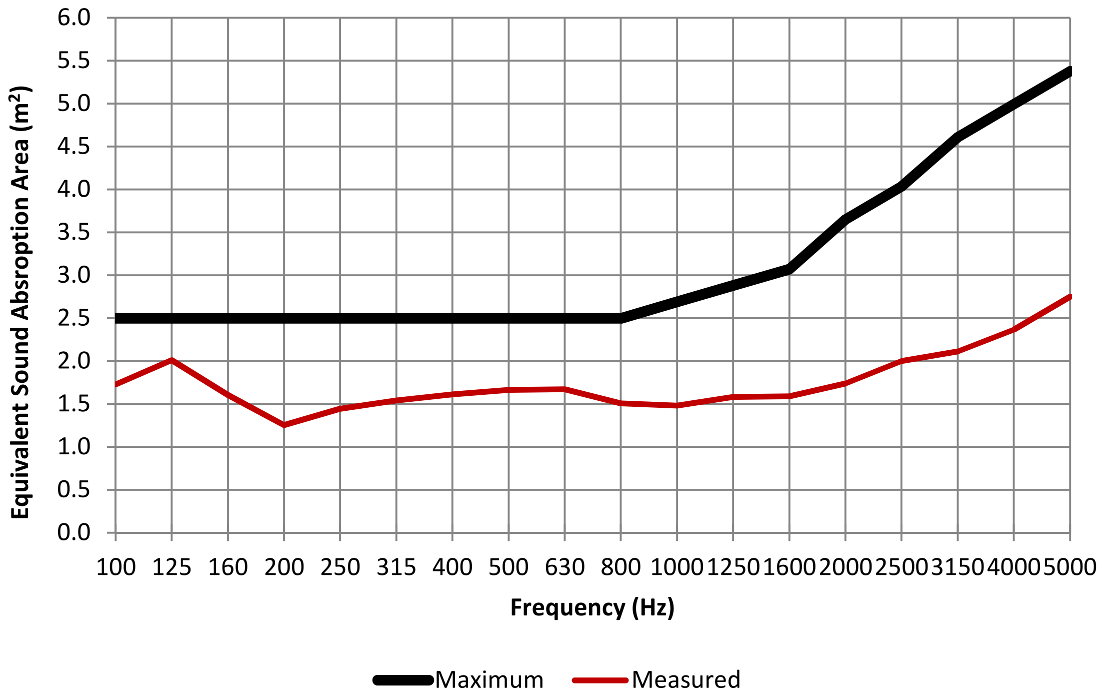
3.2 Diffusivity

The check of diffusivity was carried out in accordance to Annex A within ISO 354:2003. The test specimen used was 50 mm thick Reapor®, which meets the criteria set by ISO 354:2003 with sound absorption coefficients greater than 0.9 over the frequency range of 500 Hz to 4 kHz.

After conducting the diffusivity checks, it was found that the area (both sides) of diffusers required to achieve satisfactory diffusion was approximately 18% of the surface area of the room. This falls within the 15% to 25% prediction for rectangular rooms as stated in the ISO 354:2003 and ASTM C423-09a standards.

3.3 Equivalent Empty Room Sound Absorption Area

The equivalent sound absorption area of the empty room was measured and calculated, with the maximum values adjusted for the room volume, to ISO 354:2003 section 6.1.4 and 8.1.2.1. Although the equivalent sound absorption area is below the maximum across the entire measured frequency range, due to the room dimensions, the shape of the curve below 250 Hz shows dips and peaks measuring more than 15% from the mean of the values of both adjacent one-third-octave bands. This is shown in Graph 1.



Graph 1: The maximum and measured equivalent sound absorption area of the empty Pyrotek small-scale room

4. METHOD

Testing was carried out in accordance with ISO 354:2003, with exception to a deviation in sample size. The sample size for testing to ISO 354:2003 with a standard 200 m^3 room is between 10 m^2 and 12 m^2. In scale with the smaller volume of the reverberation room, the sample size was 2.4 m^2. The samples were mounted using Type A mounting and the perimeter was enclosed by 12.5 mm thick wood. The test specimen used for all testing was 50 mm thick Reapor®, which is a rigid homogeneous porous absorber with a density of 270 kg/m^3 manufactured from recycled glass granules. Reapor® was chosen for verification testing due to the large number of sound absorption test reports available from independent acoustical laboratories. Table 1 displays the primary details of each Reapor® sound absorption test, whilst tables 2-5 and graphs 2-5 show and compare results.

Testing was conducted using the interrupted noise method, with pink noise emitted by a Larson Davis BAS001 omnidirectional dodecahedral sound source which was amplified by a Crown XLS1000. The microphone used was a Bruel & Kjær Type 4189, with the system running through a Bruel & Kjær PULSE analyser platform. The temperature, relative humidity and atmospheric pressure were measured with a Greisinger GFTB100. Six microphone and sound source positions were measured, with three averages per position. The empty room was tested with the perimeter-sealing wooden frame in place.

The weighted sound absorption coefficient (α_w) was calculated in accordance with ISO 11654:1997 (International Organization for Standardization, 1997). The noise reduction coefficient (NRC) and the sound absorption average (SAA) were calculated in accordance with ASTM C423-09a. The 95% confidence intervals for the absorption coefficients measured within the Pyrotek small-scale reverberation room have been plotted as error bars onto graphs 2-5.

5. RESULTS

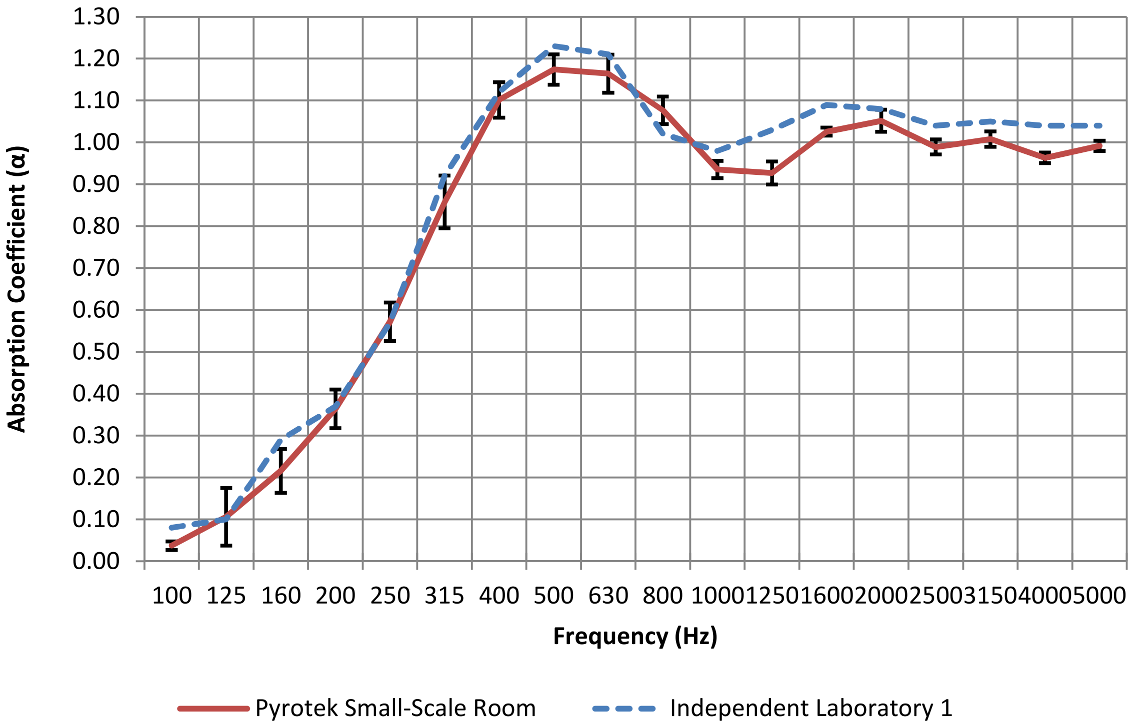
Table 1: The primary specifications of the reverberation rooms and tests referred to in this paper

	Pyrotek Small-Scale Room	**Independent Laboratory 1**	**Independent Laboratory 2**	**Independent Laboratory 3**	**Independent Laboratory 4**
Room Volume *(m^3)*	48	205	217	200	393
Total Surface Area *(m^2)*	95	261	305	236	322
Number of Diffusers	9	14	6	17	15
Type of Diffusers	Stationary	Stationary	Stationary	Stationary	Stationary
Test Standard	ISO 354:2003 (with deviance)	AS ISO 354:2006	ISO 354:2003	AS ISO 354:2006	ISO 354:2003
Temperature During Test *(°C)*	29	10	17	22	24
Relative Humidity During Test *(%)*	55	79	45	53	54
Atmospheric Pressure During Test *(kPa)*	100.9	103.1	101.1	101.3	96
Sample Size *(m^2)*	2.4	11.7	10.9	10.5	13.7
Year of Test	2016	2015	2010	2009	2005
Location	Australia	Australia	New Zealand	Australia	Germany

5.1 Independent Laboratory 1

Table 2: The absorption coefficients measured within the Pyrotek small-scale room and independent laboratory 1

Frequency *(Hz)*	**Pyrotek Small-Scale Room**	**Independent Laboratory 1**	**Difference**
100	0.04	0.08	0.04
125	0.11	0.10	0.01
160	0.22	0.29	0.07
200	0.36	0.37	0.01
250	0.57	0.57	0.00
315	0.86	0.92	0.06
400	1.10	1.12	0.02
500	1.17	1.23	0.06
630	1.16	1.21	0.05
800	1.08	1.02	0.06
1000	0.94	0.98	0.04
1250	0.93	1.03	0.10
1600	1.03	1.09	0.06
2000	1.05	1.08	0.03
2500	0.99	1.04	0.05
3150	1.01	1.05	0.04
4000	0.96	1.04	0.08
5000	0.99	1.04	0.05
NRC	0.95	0.95	**Standard Deviation of**
SAA	0.94	0.97	**Difference:**
α_w	0.90	0.90	0.03

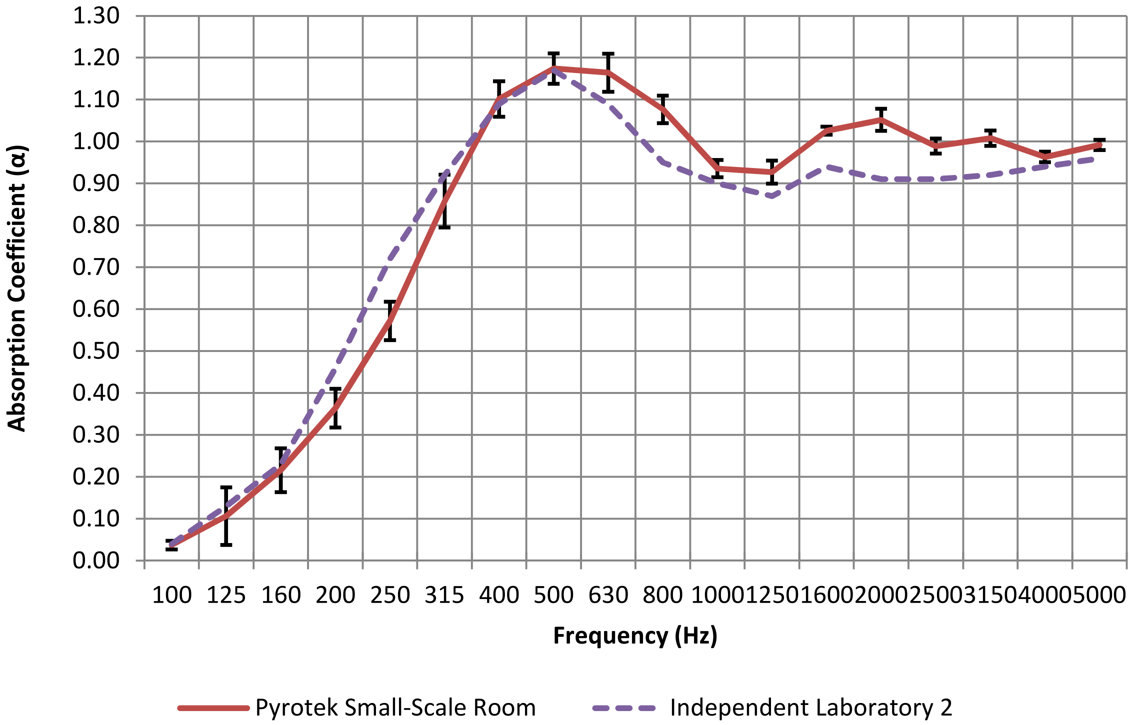


Graph 2: The absorption coefficients measured within the Pyrotek small-scale room and independent laboratory 1

5.2 Independent Laboratory 2

Table 3: The absorption coefficients measured within the Pyrotek small-scale room and independent laboratory 2

Frequency *(Hz)*	**Pyrotek Small-Scale Room**	**Independent Laboratory 2**	**Difference**
100	0.04	0.04	0.00
125	0.11	0.13	0.02
160	0.22	0.23	0.01
200	0.36	0.46	0.10
250	0.57	0.72	0.15
315	0.86	0.92	0.06
400	1.10	1.09	0.01
500	1.17	1.17	0.00
630	1.16	1.09	0.07
800	1.08	0.95	0.13
1000	0.94	0.90	0.04
1250	0.93	0.87	0.06
1600	1.03	0.94	0.09
2000	1.05	0.91	0.14
2500	0.99	0.91	0.08
3150	1.01	0.92	0.09
4000	0.96	0.94	0.02
5000	0.99	0.96	0.03
NRC	0.95	0.95	**Standard Deviation of**
SAA	0.94	0.91	**Difference:**
α_w	0.90	0.90	0.05

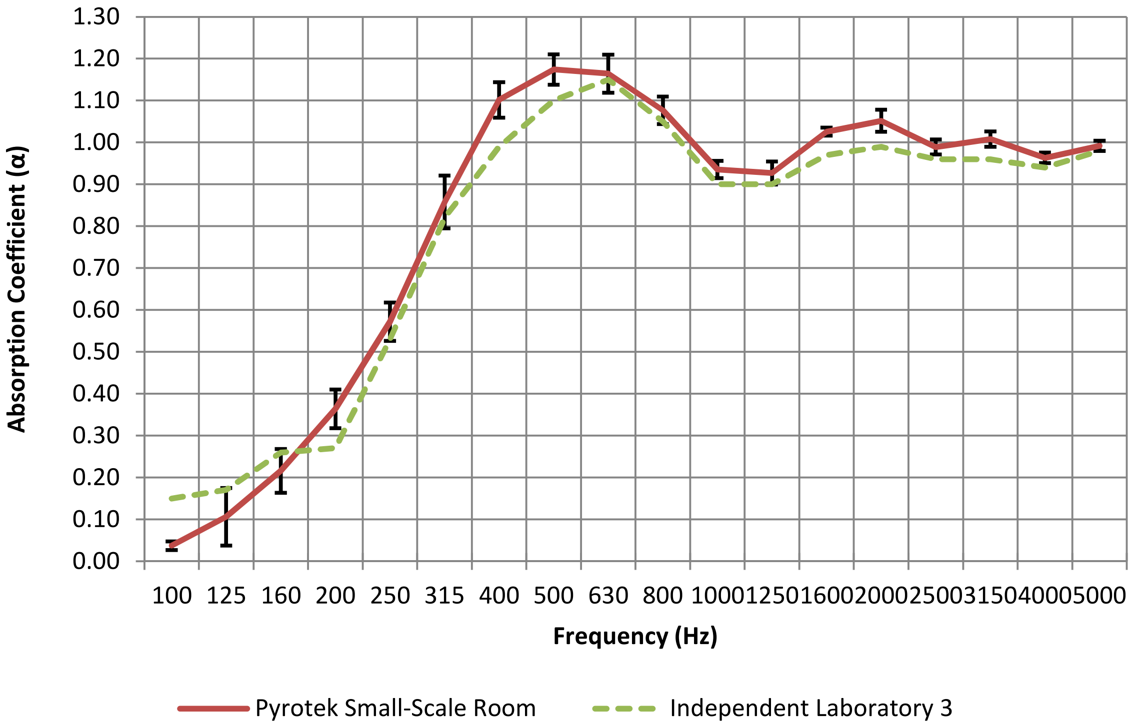


Graph 3: The absorption coefficients measured within the Pyrotek small-scale room and independent laboratory 2

5.3 Independent Laboratory 3

Table 4: The absorption coefficients measured within the Pyrotek small-scale room and independent laboratory 3

Frequency *(Hz)*	Pyrotek Small-Scale Room	Independent Laboratory 3	Difference
100	0.04	0.15	0.11
125	0.11	0.17	0.06
160	0.22	0.26	0.04
200	0.36	0.27	0.09
250	0.57	0.53	0.04
315	0.86	0.82	0.04
400	1.10	0.99	0.11
500	1.17	1.10	0.07
630	1.16	1.15	0.01
800	1.08	1.05	0.03
1000	0.94	0.90	0.04
1250	0.93	0.90	0.03
1600	1.03	0.97	0.06
2000	1.05	0.99	0.06
2500	0.99	0.96	0.03
3150	1.01	0.96	0.05
4000	0.96	0.94	0.02
5000	0.99	0.98	0.01
NRC	0.95	0.90	**Standard Deviation of**
SAA	0.94	0.89	**Difference:**
α_w	0.90	0.85	0.03

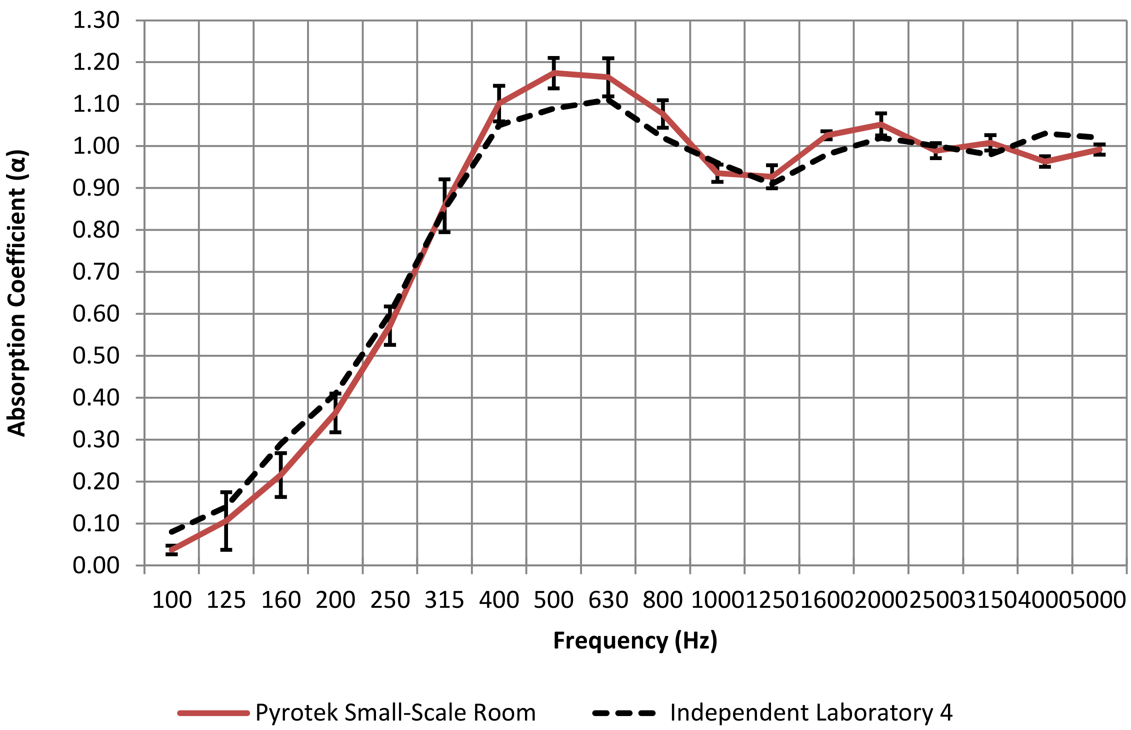


Graph 4: The absorption coefficients measured within the Pyrotek small-scale room and independent laboratory 3

5.4 Independent Laboratory 4

Table 5: The absorption coefficients measured within the Pyrotek small-scale room and independent laboratory 4

Frequency *(Hz)*	Pyrotek Small-Scale Room	Independent Laboratory 4	Difference
100	0.04	0.08	0.04
125	0.11	0.14	0.03
160	0.22	0.29	0.07
200	0.36	0.41	0.05
250	0.57	0.60	0.03
315	0.86	0.85	0.01
400	1.10	1.05	0.05
500	1.17	1.09	0.08
630	1.16	1.11	0.05
800	1.08	1.02	0.06
1000	0.94	0.96	0.02
1250	0.93	0.91	0.02
1600	1.03	0.98	0.05
2000	1.05	1.02	0.03
2500	0.99	1.00	0.01
3150	1.01	0.98	0.03
4000	0.96	1.03	0.07
5000	0.99	1.02	0.03
NRC	0.95	0.90	**Standard Deviation of**
SAA	0.94	0.92	**Difference:**
α_w	0.90	0.90	0.02



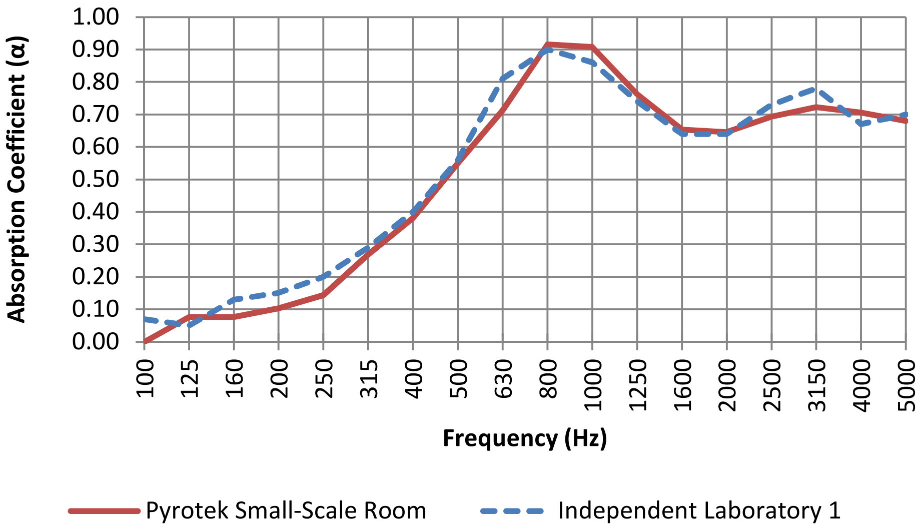
Graph 5: The absorption coefficients measured within the Pyrotek small-scale room and independent laboratory

Photograph 5 and 6: The Reapor® panels mounted within the Pyrotek reverberation room during testing

6. DISCUSSION

Whilst satisfactory correlation can be observed between the Pyrotek small-scale reverberation room and all four independent laboratories, the strongest correlation is with independent laboratory 4, as seen in table 5 and graph 5. This comparison had the lowest standard deviation of difference, an identical α_w and a minor 0.02 difference in SAA. Although the NRC differs by 0.05, the actual difference is only 0.01 before rounding to the nearest 0.05 as stipulated in ASTM C423-09a. Variance between the measured results could be caused by a variety of factors. It is plausible that the general variance in the production of Reapor® may have resulted in minor absorption performance differences. Furthermore, there is a degree of uncertainty for sound absorption measurements within reverberation rooms. Although it is not the focus of this paper, Fergus (2002), Ramis, Abla, Martínez & Redondo (2005), and many others have discussed this in detail.

The focus material used in this paper has been Reapor®, but other samples have been tested in the Pyrotek reverberation room which reveal similar correlation with full scale tests. However, at the time of writing, only non-faced porous samples have been tested and compared to independent laboratories. Throughout all of our testing, variation in low frequency accuracy has been observed, although this been an expected property of the room since inception due to the small room volume. A prime example of this low frequency uncertainty is from a test as shown in graph 6. The test specimen was 50 mm thick Viterolite™ 600, a rigid homogeneous porous absorber with a density of 600 kg/m^3, which was also tested at independent laboratory 1 to allow comparison.



Graph 6: The absorption coefficients of 50 mm thick Viterolite™ 600 measured within the Pyrotek small-scale room and independent laboratory 1

It was observed during our stages of diffusivity checks that results could appreciably differ depending on the quantity and layout of the diffusion panels. Although significant time was spent to achieve the level of diffusivity we have at the time of writing, we theorise that it could be plausible to improve the 95% confidence intervals with further adjustment of the diffusion panels. However, the small room volume and unfavourable shape of the room are factors which have a large influence on the performance of the room and cannot be controlled. For this reason, future attempts at further improving factors which we can control from this stage may be insignificant.

7. CONCLUSION

A small-scale reverberation room was successfully created where we can test the sound absorption coefficients of materials during the research and development process, before sending the final material to an independent acoustical laboratory for accredited ISO 354:2003 results. This significant development provides the benefit of accelerating the research and development process, saving both time and resources. Although the small 48 m^3 room volume causes greater uncertainties at low frequencies, it has allowed for the reverberation room to be constructed rapidly and close to the research and development department.

Table 6: A comparison of the calculated single-number absorption ratings

	Pyrotek Small-Scale Room	**Independent Laboratory 1**	**Independent Laboratory 2**	**Independent Laboratory 3**	**Independent Laboratory 4**
NRC	0.95	0.95	0.95	0.90	0.90
SAA	0.94	0.97	0.91	0.89	0.92
α_w	0.90	0.90	0.90	0.85	0.90

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