1 IN SITU MEASUREMENT OF THE SOUND ABSORPTION CHARACTERISTICS OF EXISTING BUILDING FABRICS

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2 INTRODUCTION

Sound reflections from building walls may be perceived as echoes and hence can disrupt music and speech considerably. Noise due to reflection in enclosed space impacts comprehensibility of sound. Sound absorption reduces reflection from surfaces and can improve the clarity.

The current standards do not outline a methodology to measure the sound absorption co-efficient, α, of wall surfaces in-situ. Instead sound absorption must be measured on a sample of wall, or wall material, in a reverberation chamber, or laboratory using an impedance tube, respectively.

The easy measurement of the sound absorption co-efficient, α, is pertinent for characterisation of the noise abatement abilities of built construction. Accurate acoustic modelling of existing built spaces, and design of sound retrofit measures, are dependent on correct building material characterisation.

As control of architectural materials and surfaces has improved in recent decades, architects have come to routinely specify pristine and polished surfaces. Although visually striking these lustrous surfaces promote poor acoustical performance in internal environments. Glass, smooth concrete, plastered and painted surfaces all reflect sound. Materials such as polished concrete, glass and smooth metal exhibit almost perfect reflection. In order to compensate for this absorptive panels are often specified post-occupancy by building occupants. Alternative materials could instead be specified at construction that would enable absorption of sound, particularly nuisance noise, in buildings. Soft open textures such as rock and glass wool make for good sound absorbing materials; however these do not have the strength characteristics for outer surface of walls. Instead porous concrete materials are an option. In this study a concrete with hemp aggregate, and a commercial lime-cement binder is assessed[1].

This paper presents a methodology that adapts procedures outlined in ISO-13472[2] and ISO-10534[3]. The method was tested on a range of materials in-situ and in the laboratory. The absorption co-efficient of materials in their intended location and finish are hence determined using an impedance tube. This method provided consistent measurements, with less than 5% standard deviation.

3 RESEARCH BACKGROUND

This research is concerned with the development of novel products, for internal and external, building cladding systems for new and for retro-fit buildings with the dual objectives to abate the propagation of noise and to enable energy savings in buildings through thermal insulation.

A primary responsibility of the building envelope is the mitigation of noise impacting on the internal environment. As oultined in a recent World Health Organization report instances of cardiovascular disease, tinnitus, cognitive impairment, hypertension, anxiety and sleep disorders can all be related to environmental noise[4].

Enhancement of noise in internal space via reflection from room surfaces has also been related to annoyance, comprehension, difficulty, stress etc.[5].

The common methods of measuring sound absorption from a wall are using an acoustic chamber, the probe method or an impedance tube. Of these options the PU or PP probe methods is suitable for in-situ sound absorption measurement; although accurate, the procedure can be prohibitively slow for a large test area.

Looking at other laboratory based test methods the impedance tube requires a core bore from the built wall or for a sample to be produced. The sample may not perfectly within the mouth of the tube. Unless the sample is cut directly from the wall material the cast nature of the sample may have a different inherent constituency. This method is also limited by the thickness of the sample, which according to Laukaitis and Fiks is an influential factor[6]. It has been proposed by other authors that the impedance tube method is unsuitable for porous materials, non-homogenous and or asymmetric materials[3,7].

The most general method, documented in the literature, to determine the sound absorption co-efficient of a material is to use either an anechoic or acoustic chamber[7]. A replica wall is built and placed in the test area. Replication of a specific piece of wall may not be materially consistent and the use of an anechoic or acoustic chamber prohibits the testing of built construction. Studies have been done in the past to characterise the absorption coefficient of fibrous materials[8], porous concretes including hempcrete[9], aerated autoclaved concrete[6], concrete using recycled waste concrete aggregate[10] and porous concrete with grains of irregular size[10]. These are all material studies and were not undertaken on built construction. These authors have used a range of techniques to analyse the sound absorption characteristics including; sample within impedance tube[8,9], and the Kundt's tube method[7].

Other authors have outlined methods to calculate the absorption coefficient in rooms by Garai *et al*[7] and horizontal surfaces Londhe, *et al*[11]. and Kuipers, *et al*[12].

ISO standard 13472-1[13] outlines a method for measuring the extended surface of a road. This test method requires the surrounding area to be free from obstructions; this would not always be possible for testing of walls due to the close proximity of the ground in some instances. The test procedure explains herein was developed for use on small panels which came under the minimum surface area specified within this standard. ISO standard 13472-2[2] for the measurement of road sound absorption provides a method for using an impedance tube, for reflective surfaces. The methodology outlined in ISO 13472-2[2] combined with ISO 10534-2[3] were adapted to develop this procedure to use an impedance tube to measure the sound absorption co-efficient of walls.

4 EXPERIMENTAL PROCEDURE

4.1 METHODOLOGY

The methodology presented in this paper was developed to allow the sound absorption co-efficient of wall and barrier structures to be measured in situ. The procedure used adapts the ISO standards ISO 10534-2:2001[3] and ISO 13472-2:2010[2].

The equipment listed in Table 1 was set up as in Figure 1. The signal generator produced white noise; the speaker was allowed to run for approximately 10 minutes to get to operating temperature prior to testing. The gasket on the impedance tube was compressed into the surface of the wall to ensure an air tight seal. The test surface should have no irregular voids or cavities and be middle of the test area to minimise edge effects. The signals from the microphones are recorded for 10 seconds using a data acquisition unit and processed using Labview software and; this was repeated three times at each location. The test was conducted at other locations on the surface to account for non-homogeneous materials.

The measurement of the sound absorption co-efficient using methods outlined in ISO 13472-1[13] and used by Londhe *et al*[11], were deemed unsuitable for conducting in-situ measurements on walls, due to vertical orientation of the walls and the close proximity to the ground of the test site.

4.2 APPARATUS

The details of the equipment used to conduct the test procedure are listed in Table 1.

Table 1
Equipment Specifications

Description	Manufacturer	Model
Noise generator	Bruel and Kjaer	Type 1405
Amplifier	QSC Audio	USA 370
Data Acquisition Unit (DAQ)	National Instruments	USB-4431
Sound and Vibration Array Microphones	G.R.A.S	Type 40PR
Speaker	Visaton	FRS8, 4Ω
Impedance tube	Manufactured in TCD	N/a
Laptop	Dell	Latitude 2100

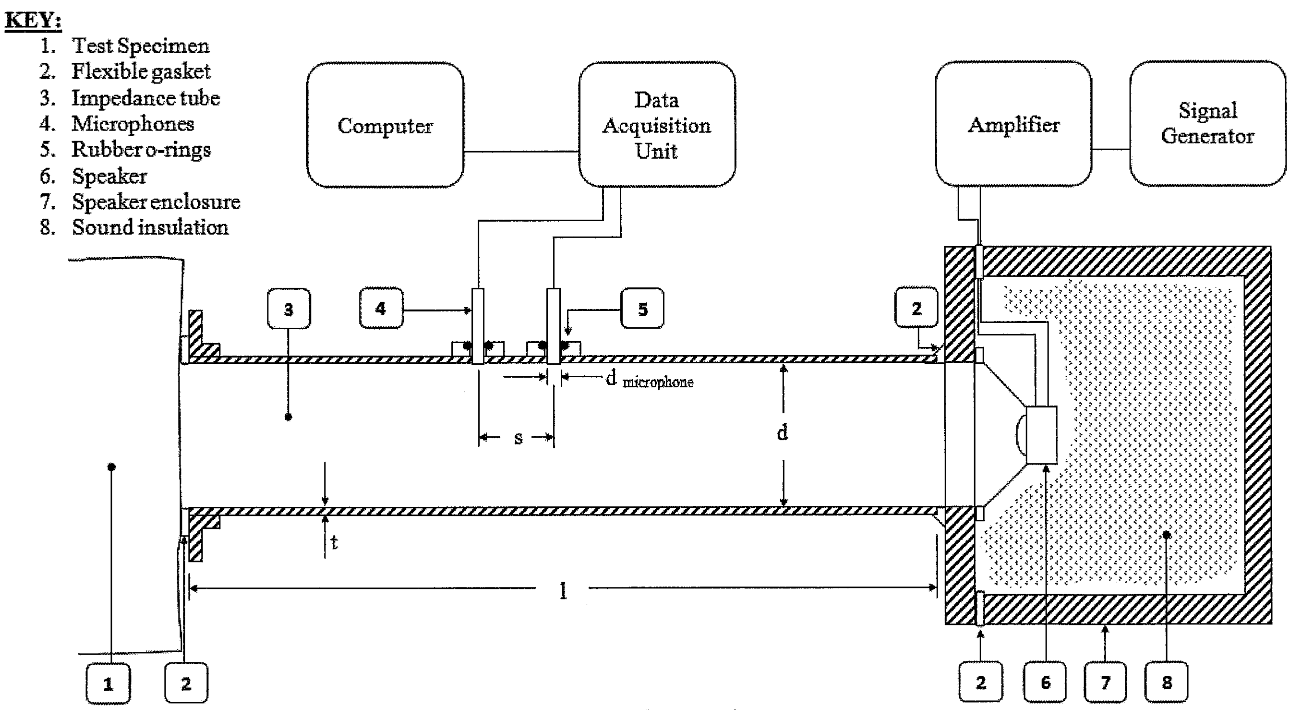


Figure 1 Configuration of impedance tube and measuring equipment

Figure 1 illustrates the arrangement of the apparatus used to measure the sound absorption of the walls, facades and panels in-situ. Vibration isolation gaskets were used between impedance tube and the test surface, similarly this was done between the impedance tube and the speaker enclosure. The apparatus was also isolated from surface where the equipment was resting; this was to reduce interference from vibrations due to external sources. This is not shown in Figure 1 for purposes of clarity in the figure.

The specifications of the impedance tube used are outlined in Table 2, the essential measurements of the impedance tube are included in Figure 1.

Table 2
Dimensions of the impedance tube

Description	Notation	Value
Internal diameter of tube	d	70 mm
Length of tube	l	963 mm
Impedance tube wall thickness	t	3 mm
Microphone diameter	$d_{microphone}$	7 mm
Spacing between microphones	s	43 mm

The test procedure used adapted versions of applicable ISO standards; this was also true for the impedance tube[2,3]. Where the impedance tube used did not meet the criterion outlined by ISO 10534-2[3] these items are listed in Table 3.

Table 3
Deviations from the requirements stipulated in ISO 10534-2:2001 for the impedance tube[3].

	ISO Requirement	Deviation from ISO requirement
1.	$d < 0.58\lambda_u$ Equation 2 (ISO 10534-2:2001, p4).	d is 0.0004m smaller than the criteria allows. This difference is deemed to be negligible in this instance.
2.	$f_u\, d < 0.58\, c_0$ Equation 2 (ISO 10534-2:2001, p4).	There is a difference of 5.28%; although this does not meet the specified criteria, it is deemed to be acceptable.
3.	"The test specimen shall fit snugly in the holder". (ISO 10534-2:2001, p8).	Due to the nature of the test specimen, this was not possible. A seal was formed at the entrance to the impedance tube with the test specimen.

Point 3 of Table 3 is the premise of this paper; it was unfeasible for the sound absorption coefficient of particular walls to be measured by removing a specimen for testing. Producing a test specimen of the wall was not viable, because the walls were of a unique construction. Replication of the wall in specimen form would have been unrepresentative of the wall and therefore been inaccurate.

4.3 WALL MATERIALS

A range of wall materials were selected to demonstrate how the sound absorption co-efficient, α, and the reflection factor, r, differ across the frequency spectrum from 250Hz to 2000Hz. The wall materials used are outlined in Table 4.

Table 4
Approximate properties of the wall materials under test

Frequency (Hz)	Hardwood	Fair - Faced Conc. Block	Painted Conc. Block	Rendered Block	Hemp lime wall
Density (kg/m^3)	650	c 2400	c 2400	n/a	583
Finish	unvarnished, treated wood	rough, unpainted	painted, surface pores	speckled, unpainted	porous, unpainted

5 RESULTS

The results outlined in Table 5 represent the average of measurements for the absorption co-efficient from various surfaces.
Table 5
Absorption Co-efficient and noise reduction for the wall materials measured in-situ.

Frequency (Hz)	Wooden finish	Fair - Faced Conc. Block	Painted Conc. Block	Rendered Block	Hemp lime wall
250	0.043	0.539	0.108	0.042	0.943
500	0.053	0.442	0.124	0.041	0.587
1000	0.044	0.372	0.070	0.038	0.454
2000	0.127	0.421	0.149	0.104	0.367
NRC	0.07	0.44	0.11	0.06	0.384

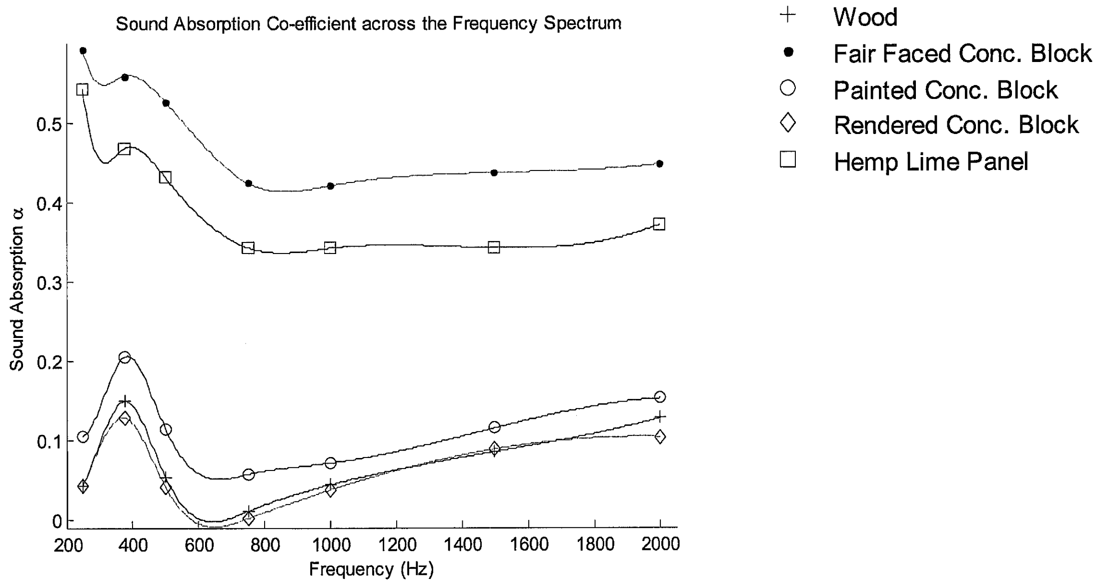


Figure 2 Sound absorption co-efficient for wall materials across the frequency spectrum

Table 6
Reflection factors for the wall materials measured in-situ.

Frequency (Hz)	Wooden finish	Fair Faced Conc. Block	-	Painted Conc. Block	Rendered Block	Hemp lime wall
250	0.409	0.324		0.224	0.381	0.239
500	0.978	0.651		0.945	0.974	0.675
1000	0.973	0.696		0.936	0.979	0.755
2000	0.978	0.766		0.965	0.978	0.811

Figure 3 illustrates the reflection factor for the five wall materials under examination.

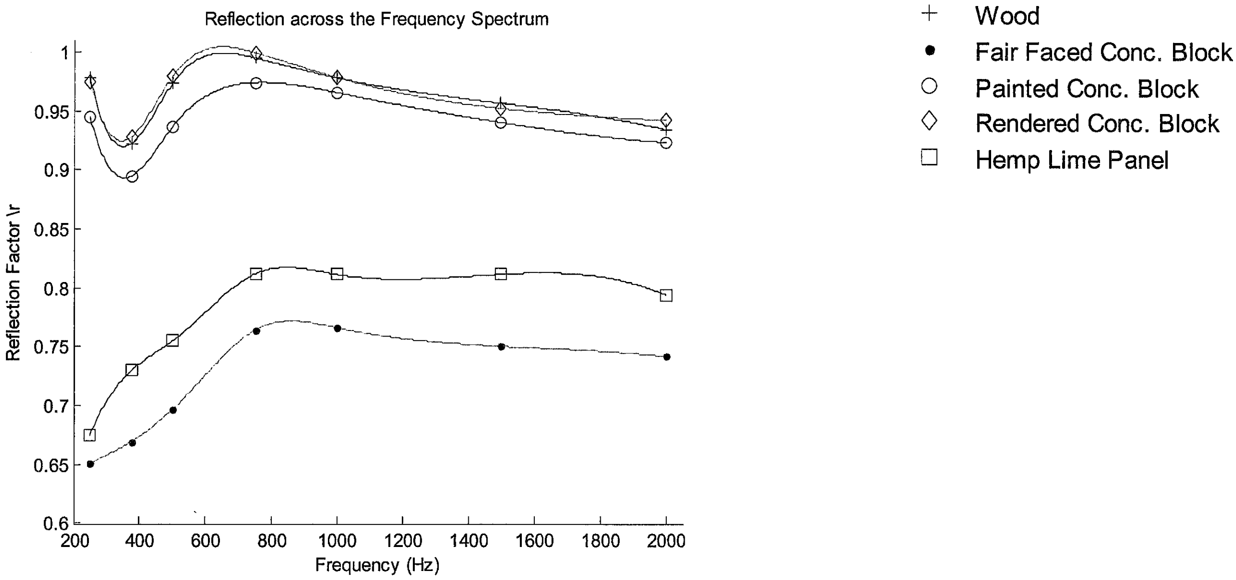
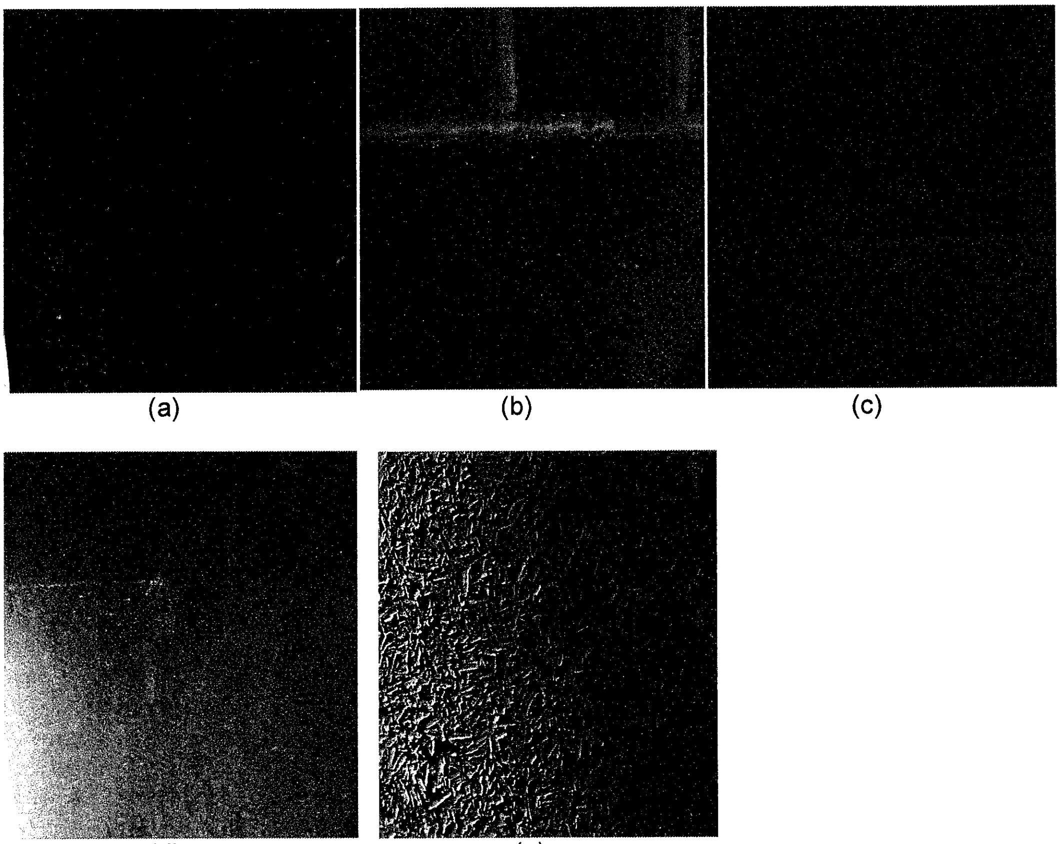


Figure 3 Reflection Factor for wall materials across the freqeuency spectrum



(a) (b) (c)

(d) (e)

Figure 4 Photographs of the in-situ walls used during testing (a) wooden finish, (b) fair-faced concrete block, (c) painted concrete block, (d) unpainted rendered wall, and (e) hemp lime panel with a commercial binder

6 DISCUSSION OF RESULTS

Using the adapted ISO methodology outlined in this paper the repeatability of the results were found to have less than 5% standard deviation.

It should be noted that given the equipment used the NRC values appear to be higher than published figures[14]. These published figures are recorded from tests in a reverberation room or anechoic chamber, which are known to output higher absorption values[7,15]. The slightly high nature of the measurements in our study can be attributed to the frequency range of the impedance tube, the influence of external sounds and the absorptive nature of the gasket used. The impedance tube available had a frequency range of 288Hz to 2,989Hz. The values below 288Hz are understood to be higher than should otherwise be expected; taking this into consideration would bring the measured values closer in line with published figures.

Testing conducted by Laukaitis and Fiks[6] highlighted that the thickness of a sample influences the absorption co-efficient; however sample thickness is not a limiting factor using this in-situ test method[6].

7 CONCLUSION

This paper presents an accurate and efficient method of sound absorption measurement in situ. Existing methods to calculate the absorption co-efficient of a wall in a laboratory require a sample of wall to be produced. However, this limits the testing to reproduced construction samples or cut outs from the building material. This is not always achievable particularly in the case of historic buildings for instance. The methodology presented in this paper allows the absorption co-efficient to be measured without damaging or affecting the surface characteristics of an already built wall. The results showed good consistency for different test locations on the wall surfaces.

The ISO 10534-2[3] standard calls for symmetrical, homogenous test specimen. The method presented in this paper does not limit the tester to sample numbers or particular physical characteristics, but instead adapts to allow the measurement of non-homogeneous and unsymmetrical rough finish of test surfaces[3].

While PU and PP probes are effective methods of in-situ measurement of the sound absorption co-efficient[12,16]. The method outline in this paper is proposed to offer a more time effective and simpler solution.

With regard to the walls tested, the hemp-lime concrete and the fair-faced concrete blocks exhibited the lowest reflection characteristics across all frequencies. Other wall types display high reflection approximating perfect reflection at 500 Hz (Figure 3). In the case of the fair-faced concrete block the low reflection is attributed to the rough surface geometry featuring surface pores. Hemp-lime concrete is shown to have an extensive multi-pore structure[9]. This enables high sound absorption for a concrete material. The porosity measured at approximately 70% ensures the sound enters the pores where it is converted to heat via friction[1,17]. Further research looks to document the absorption characteristics for a range of hemp-lime concrete mixes to analyse the optimum for sound absorption.

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