Proceedings of the Institute of Acoustics & Belgium Acoustical Society
Noise in the Built Environment, Ghent, 29-30 April 2010

VARIATION IN FIELD MEASUREMENT OF AIRBORNE SOUND INSULATION OF LIGHTWEIGHT TIMBER FLOORS

W.A.Whitfield Acoustics Research Unit, School of Architecture, University of Liverpool
B.M Gibbs Acoustics Research Unit, School of Architecture, University of Liverpool

1 INTRODUCTION

Apparently identical separating floor constructions can give significantly different results when tested in the field for sound insulation under ISO Standards. The differences may be due to variations in the surface area of the test elements or the volumes of the room. Where rooms are identical the differences are due to other factors such as measurement uncertainty or "part to part" variation caused by the construction process. This paper compares and contrasts the variability in field measurements of a lightweight timber floor construction with lightweight flanking elements with that of a concrete floor construction which had masonry/concrete flanking elements. Factors where the floor construction appears to be contributing to the difference in performance are identified.

The airborne sound insulation test data used in this paper come from two field trial test experiments. One carried out by Craik & Steel [1] in 1988 on a floor construction consisting of 125mm precast concrete with 40mm in-situ screed. The other was carried out by Whitfield et al in 2009 on a common separating timber floor construction. The test and analysis method of the latter study followed the same approach as the former study of Craik and Steel although the sample sizes and test methods are different.

One of the aims of the research was to contrast the experimental data for the two different floor constructions and identify the possible causes of any variability or differences in the test data. The test data for the lightweight floor were compared with the test sample and "control" curves produced by Craik & Steel; see Figs 1 and 2.

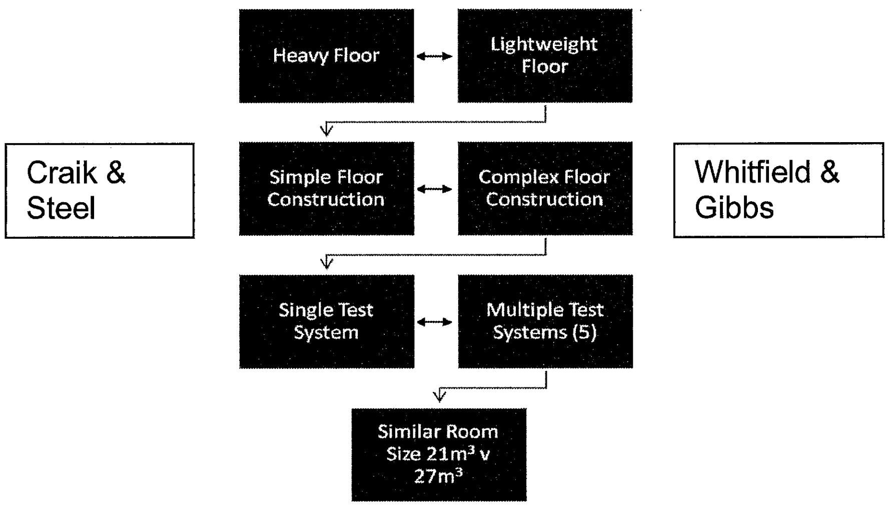

Figure 1: Comparison of Field Measurement Studies

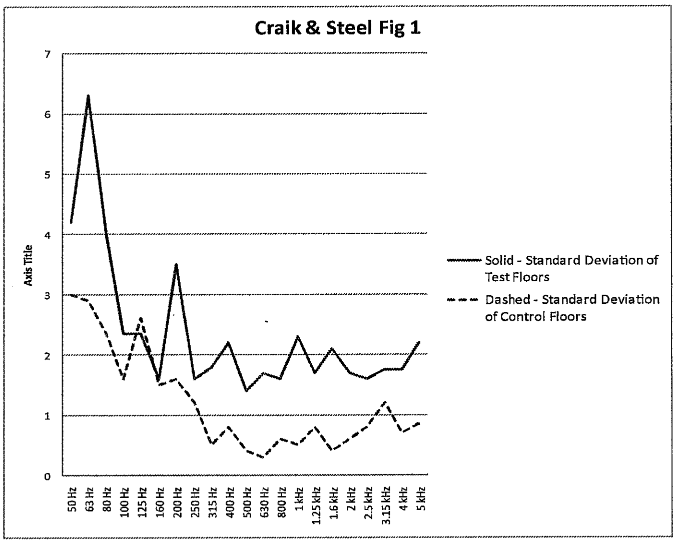

Figure 2: Standard deviations of field measurement from [1].

2 FIELD TEST MEASUREMENT

2.1 Construction

Lightweight Construction:

The floor element tested was a timber construction which from the top down consisted of:

Floating Floor: FFT1: 18mm t&g flooring boards, plasterboard layer 13.5Kg/m2, resilient deep batten min depth 70mm, mineral wool quilt in void between battens 25mm deep min density 10Kg/m3;
Floor decking: 18mm thick wood based board (min density 600M^3/Kg);
Joists: 253mm metal web joists;
Absorbent Material: 100mm deep mineral wool quilt insulation between joists;
Ceiling: CT3 2 x 10mm layers of plasterboard (nominal 12Kg/m2) coupled with 25mm metal resilient bars.

Also see Fig 3 below:

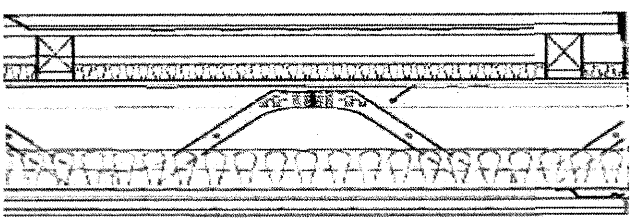

Figure 3: Light weight floor section showing floor element makeup

The flanking elements were also of light weight construction and were made up of:
External wall & Separating wall: 2 x layers of 12.5mm thick plasterboard min mass 22Kg/m2;
Internal walls: 1 x layer of 15mm plasterboard either side of 90mm metal stud.

2.2 Test Procedure

Background

For comparison, the tests were carried out on a residential scheme similar to that tested by Craik & Steel. The floor elements were between matched room pairs. This study differed from that of Craik and Steel in that five individuals were used, each with their own test systems. An aim of this approach was to highlight systematic deviations in the measurement and thus the variability in measurement test data.

Each "test system" comprised an individual operator and test equipment. Each "test system" was employed for six notionally identical room pairs, to determine the performance of the separating floor. In all the six room pairs were tested on three separate occasions over the space of three days. This resulted in eighteen sound insulation test results for each test system.

In addition to the six floor pairs tested a separate room pair was used for a repeatability experiment. Craik & Steel measured a control floor, between the test floors, but practical limitations precluded a similar alternating approach in this study.

Site Testing

The tests were carried out in a typical room type which was a small bedroom that measured 5.035m long x 2.975m wide x 2.4m high with an approximate room volume of 27m3. Six identical room pairs were selected across the development. See Fig 4 below:

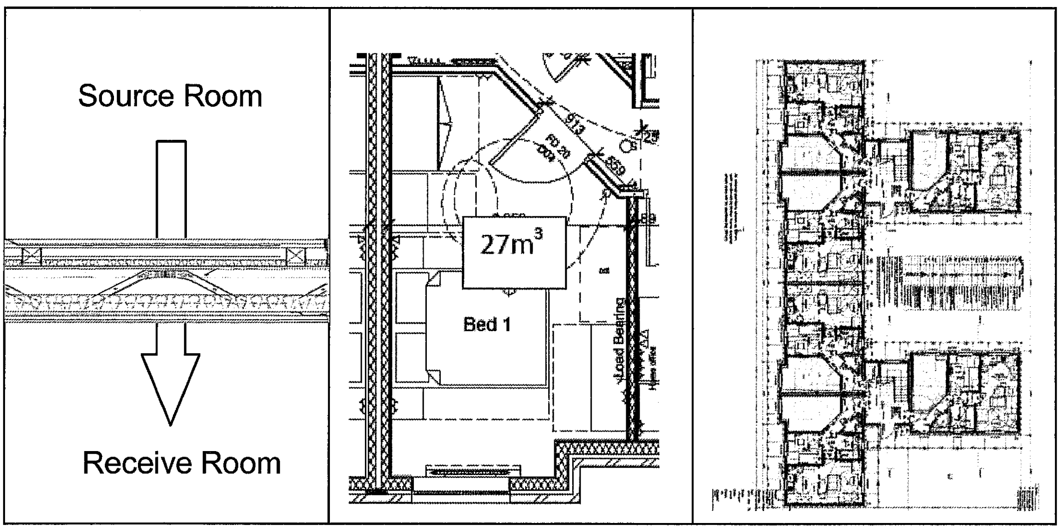

Figure 4: Matched room pairs, room shape & volume and location on site plan.

The rooms were complete with bare wood floor, plasterboard wall and ceiling surfaces and all were unfurnished.

The measurement method was designed to represent the sampling approach in the field during a normal operational day. Use was made of a residential housing site which was nearing completion and where the majority of work had ceased and therefore noise interference from site activities was minimised. The test method followed the ISO 140 [2] standard, using the static microphone sampling method for both source and receive room positions. The sampling regime used 5 sound pressure level monitoring positions with a 6 second duration test sample in each position. The reverberation times were taken in each room survey using 3 static microphone positions and measuring reverberation time twice in each position. In total 90 sound insulation tests took place on the 6 room pairs. In addition, 30 tests took place on the repeatability room pair (each measurement system measured the room pair 6 times each).

Care was taken to ensure that the noise from each test did not interfere with the measurements of another. For this reason room pairs were selected in different blocks of the housing scheme.

Test data was collated for each of the 5 measurement systems used and the 1/3rd octave band R' levels calculated. Again, this followed the method used by Craik and Steel. The standard deviation was calculated for each 1/3rd octave band from 50Hz to 5KHz on each day, then averaged over the three days to give a test system average.

3 RESULTS

The single-value airborne sound insulation performance of the timber floor, over all tests, is as follows:

Reproducibility - Parameter	**dB R'_w**	**dB $D_{nT,w} + C_{tr}$**
Min	60	46
Max	65	58
Range	5	12
Mean	62.6	53.2
Standard Deviation	0.99	2.29

The distribution of the results appears to be symmetrical with the mean value approximately in the middle of the range, suggesting a Gaussian distribution for the sample. Considering the sampling approach taken and the number of samples collected this was expected.

The single-value airborne sound insulation performance of the control floors are as follows:

Repeatability - Parameter	**dB R'_w**	**dB $D_{nT,w} + C_{tr}$**
Min	61	48
Max	65	57
Range	4	9
Mean	63.2	54.1
Standard Deviation	0.95	2.20

In this case the distribution has a mean within 1dB of the test sample floors and a slightly smaller standard deviation. This is a reasonable result and again was expected.

In order to compare the performance of the lightweight timber floor with the heavyweight concrete and masonry, a more detailed analysis of the data in third octave bands, is required.

4 DATA ANALYSIS

The test data was collated for each of the 5 measurement systems used. Source, receive and background sound pressure levels together with the reverberation times for each test were analysed and the 1/3rd octave band R' levels calculated.

For each test system (1 to 5) and in line with the method used by Craik & Steel, the standard deviation was calculated for each 1/3rd octave band from 50Hz to 5KHz, for measurements on each day, in the 6 room pairs. The three standard deviations are tabulated between 50Hz and 5KHz in Table 1 in the Appendix.

The standard deviations were then averaged over the three days to give the individual Test System average in each 1/3rd octave band. This test system average sound insulation standard deviation was used for comparison with the "10 test floors" used by Craik and Steel. An example of this is detailed in Fig. 5.

		50 Hz
Tester/System	Test Day	
1	1	1.29
1	2	2.05
1	3	2.27
Test System 1: Repetition SD		1.79
Tester/System 1: Ave SD		1.87

Daily standard Deviation for 50Hz for test system 1 over 6 floor tests

Repeatability test standard Deviation

Daily Average standard Deviation

Figure 5: Tabulated Representation of Test Data Standard Deviations.

The individual test system standard deviations, for the third octave bands between 50Hz and 5KHz, are represented for the control repeatability and test sample reproducibility in Fig. 6.

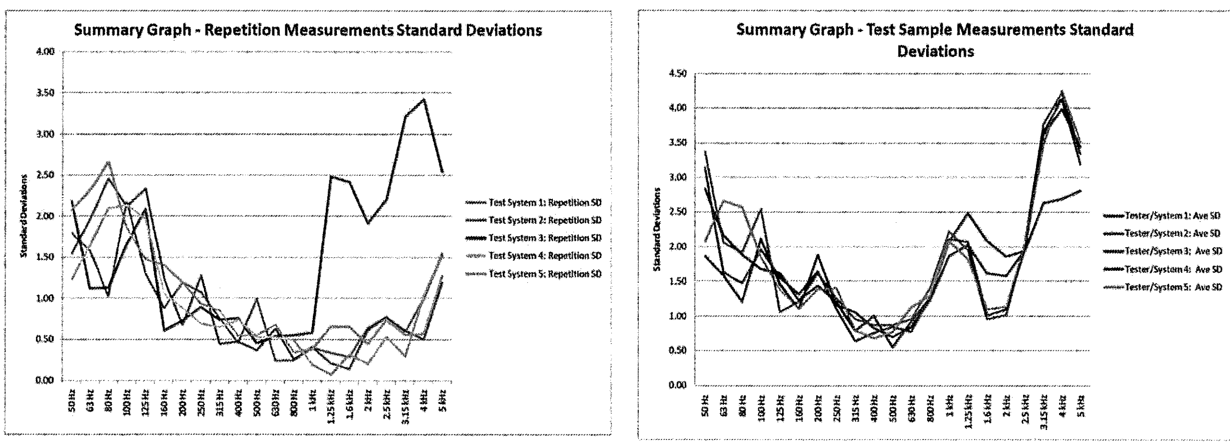

Figure 6: Repeatability and Reproducibility standard deviation curves for all 5 test systems

For the control repeatability, only one test sample curve differed significantly from the general curve pattern and this belonged to Test System 3 (red line in Fig. 6) which exhibited a significant increase in the standard deviations after 1000Hz. The explanation for this jump is not clear except that it is out of step with all the other test systems involved in the light weight floor tests.

For the test sample reproducibility, the standard deviations have a much similar curve shape. It is noted that there is a sharp increase at 2500Hz. Both the average reproducibility and repeatability average curves are compared with the Craik & Steel results in Fig.7 and 8 respectively.

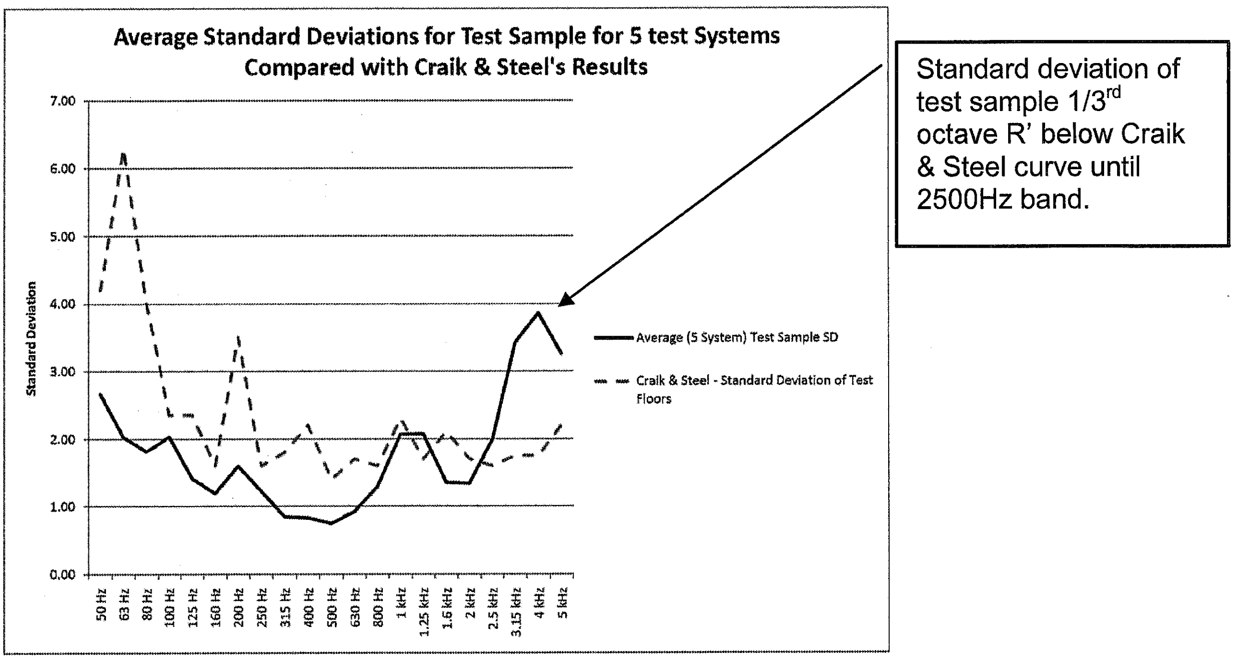

Figure 7: Comparison of test sample data – Light & heavy floor constructions

Both the heavyweight and lightweight results exhibit higher standard deviations at the low frequency range, decreasing gradually towards the mid frequency bands 400-500Hz. The results for the lightweight floor exhibit distinctive characteristics in that the averaged curve rises to approximately 2 standard deviations at 1000Hz and 1250Hz then falls to a unit value at 1600 and 2000Hz before rising steeply to peak at approximately 4 s.d. at 4000Hz. In contrast the heavy weight floor experiment standard deviation is relatively constant at about 2 s.d. between 250 – 5000Hz. It is noted that the lightweight floor reproducibility generally has lower standard deviations across the majority of the frequency range 50Hz – 2000Hz.

The average standard deviation of the lightweight timber floor experiment is generally at or below the test sample curve of Craik and Steel, up to 2500Hz, above which a sharp rise is observed. This result for the test sample is contrasted with the control case when the two standard deviation curves are very similar in shape, again deviating at the extreme low and high frequency range.

The increase in standard deviations for the light weight floor above 2000Hz was observed in 4 out of the 5 test systems used. A possible reason for the increase is due to flanking transmission. The flanking walls are of studwork construction and present regular structural discontinuities to the vertical vibration transmission. The upper parts of the walls in the receive room therefore will radiate more sound than the lower parts. This would not be the case in the source room where the sound field is propagated from the sound source in the corner and irradiates the room surfaces diffusely. This explanation has yet to be experimentally confirmed or otherwise and this is to be undertaken in future work.

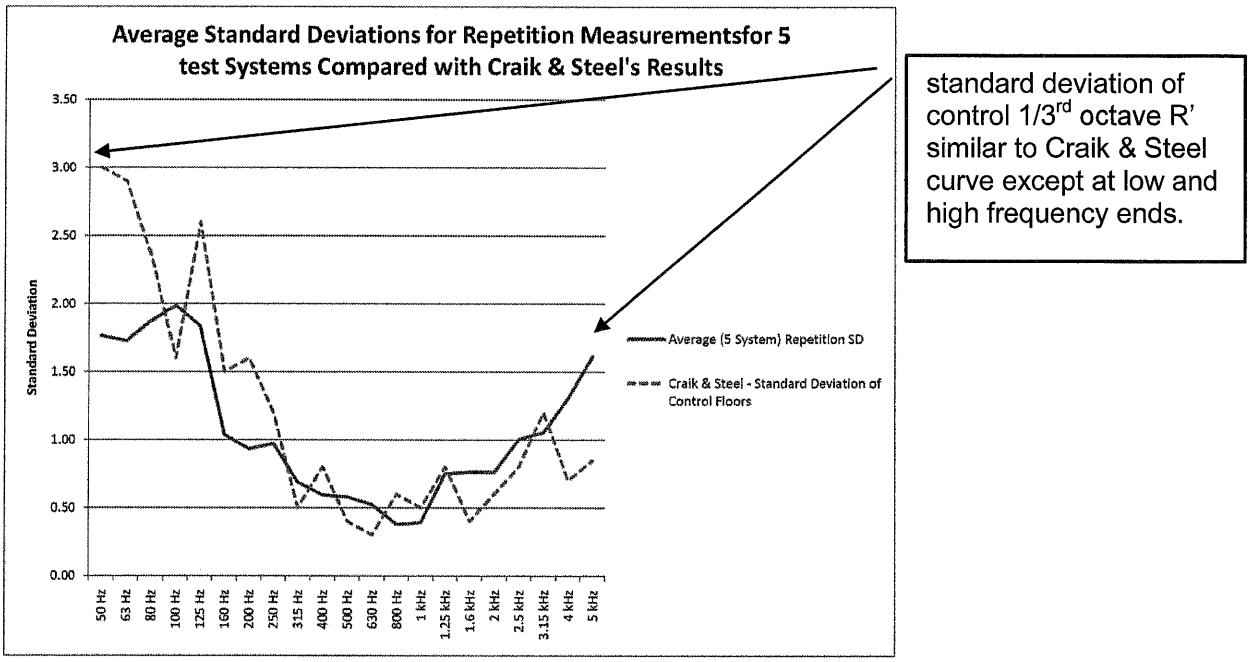

Figure 8: Comparison of "control floor" test variability for measurement systems

Generally the standard deviation of the repeatability tests performed on both the heavy and light weight floors exhibit similar curves both of which are higher at the low frequency range 50 – 125Hz, falling gradually to the mid range frequencies 500-1600Hz before rising again at high frequency. They indicate that the test systems used for both the Craik & Steel and Whitfield & Gibbs experiments had similar variability characteristics. The only notable differences were at the extreme ends of the frequency range where the Craik and Steel data showed higher standard deviations in the low frequency bands, probably due to the fact that they had a smaller test room and for the light weight floor data in the high frequency bands which is possibly due to the contribution of the flanking elements in the receive room.

The test data for the complex lightweight timber floor system can now be assessed using the same method used by Craik & Steel in determining the variability due to "workmanship" of the simple concrete floor.

5 DISCUSSION

The standard deviation of the control and the test sample data was used by Craik and Steel to identify the average variance over a defined frequency range. The relatively high standard deviations below 250Hz were thought due to the smallness of the room. Therefore the analysis was limited to the 14 third octave bands in the range 250 – 5000Hz. The average standard deviation is computed from the average variance across this range. Then by deducting the variation due to the measurement procedure (by subtracting the variances), the variation in sound reduction index between identical test floors gives a standard deviation of 1.7dB.

This method was replicated across the same frequency range for the lightweight timber floor system. The results for this frequency range are detailed in Table 1.

Table 1: Average SD (250-5000Hz)

	Actual From Paper	Ave SD	Average Var	Sum Variance
Whitfield & Gibbs		0.88	0.77	10.83
Whitfield & Gibbs		2.06	4.24	59.39
Craik & Steel	1.84	**1.83**	3.36	47.06
Craik & Steel	0.73	**0.74**	0.55	7.64
		Ave SD (dB)	Average Var	
	1.7	**1.7**	2.82	Craik & Steel
		1.9	3.47	Whitfield & Gibbs

Using the range 250 – 5000Hz the comparison between the heavyweight and lightweight floors is between 1.7dB and 1.9dB respectively, a difference of 0.2dB between the floors over the specified range of frequencies (250-5000Hz) which should be the part of the spectrum which exhibits a relatively low standard deviation of results. In the case of the lightweight floors, the slightly higher average standard deviation is mainly due to the significantly higher standard deviations in and above the 2500Hz third octave band.

This indicates that in general both floors either have relatively good workmanship, or at least they are as good/bad as each other, even though the lightweight timber floor is more structurally complicated.

Based on the range of data collected during the experiment it is worth considering two further situations:

1) The average standard deviation across the full frequency spectrum 50 – 5000Hz
2) The average standard deviation across the standard sound insulation test range i.e. spectrum containing 16 third octave bands 100 – 3150Hz

For the former case the results are detailed in Table 2.

Table 2: Average SD (50-5000Hz) - Full Range

	Actual From Paper	Ave SD	Average Var	Sum Variance
Whitfield & Gibbs		1.19	1.41	29.68
Whitfield & Gibbs		2.00	4.00	83.96
Craik & Steel	**1.84**	**2.64**	6.96	146.24
Craik & Steel	**0.73**	**1.46**	2.13	44.71
		Ave SD (dB)	Average Var	
	1.7	**2.2**	4.84	Craik & Steel
		1.6	2.58	Whitfield & Gibbs

In this situation the lower standard deviations for the lightweight floor tests at frequencies below 250Hz compensate for the higher standard deviations at 2500Hz and above. The variation between "identical" floors is 2.2dB for the heavyweight floors and 1.6dB for the lightweight floors over the full frequency range 50 – 5000Hz. In a similar manner the same can be done for the standard sound insulation test range for field testing in England and Wales. In this situation the 16 third octave bands between 100 – 3150Hz are selected and the average standard deviation computed for both situations. The results are detailed in Table 3.

Table 3: Average SD (100-3150Hz) - Standard SI Test Range

	Actual From Paper	Ave SD	Average Var	Sum Variance
Whitfield & Gibbs		0.99	0.99	15.77
Whitfield & Gibbs		1.66	2.75	44.00
Craik & Steel	**1.84**	**2.02**	4.06	65.01
Craik & Steel	**0.73**	**1.13**	1.29	20.56
		Ave SD (dB)	Average Var	
	1.7	**1.7**	2.78	Craik & Steel
		1.3	1.76	Whitfield & Gibbs

In this situation the lower standard deviations for the lightweight floor tests at frequencies below 250Hz and the truncation of the very high frequencies which also exhibit high standard deviations, give the variation between identical floors as 1.3dB for lightweight floors compared with 1.7dB for the heavyweight floors. Again some allowance should be made for the fact that the lower frequencies vary more in the heavyweight case because of the smaller room.

In general, the variability does not appear to be significantly affected by the complexity of the floor construction. It may be the case considered is one of particularly good workmanship. It is also worth noting that the standard deviations above are aggregate scores (the average of 5 test systems) Craik & Steel used only one which might contribute to a slightly skewed result.

6 CONCLUSION

An analysis of field measurement of sound insulation of lightweight timber floors has been undertaken for 5 separate sound insulation test systems. A high degree of confidence can be attached to the variability data for both the control (repeatability) results and the test sample (reproducibility) results as almost all the data collected from the 5 test systems exhibited almost identical frequency dependent characteristics. This was particularly the case in the reproducibility results. The repeatability results also indicated that the test systems used in both experiments had similar variability which was low in both cases.

The variability in airborne sound insulation test performance was compared between the heavyweight and light weight floor systems.

In the first comparison, which replicated the calculations of Craik & Steel, the average variability due to workmanship was 1.9dB for the complex timber floor as opposed to 1.7dB for the simple concrete floor.

Two further comparisons were made across the full frequency range 50 – 5000Hz and over the test range 100-3150Hz. In both cases the lightweight floor element test data demonstrated gave workmanship variability, 1.6dB as opposed to 2.2dB for the heavyweight system in the first case and 1.3dB as opposed to 1.8dB in the second.

The test data implies that either the workmanship on this site is particularly good or the floor construction itself, even though relatively complex, does not appear to have a significant part in the variability of test data. In two out of the three comparisons made it has lower variability than the simplest concrete floor construction.

7 REFERENCES

1. Robert J. M. Craik & John A. Steel, - The Effect of Workmanship on Sound Transmission through Buildings - Part 1 - Airborne Sound : Applied Acoustics 27 p57-63 – 1989.
2. BS EN ISO 140-4: 1998 – Acoustics – Measurements of sound insulation in buildings an of building elements: Part 4: Field measurements of airborne sound insulation between rooms.

8 APPENDIX TABLE

Apparent Level Difference R' Standard Deviations Summary Per System

	Tester/System	Test Day	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	315 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz	2.5 kHz	3.15 kHz	4 kHz	5 kHz
BW	1	1	1.29	1.95	1.69	2.82	2.69	0.92	1.98	1.27	1.26	0.58	0.53	0.93	1.39	1.92	1.76	1.27	0.99	1.68	3.25	3.76	2.96
BW	1	2	2.05	2.02	1.03	2.37	0.73	1.64	1.85	1.03	0.87	0.84	0.67	0.84	1.11	2.00	1.89	1.10	1.17	1.74	3.39	3.52	2.18
BW	1	3	2.27	0.80	0.90	1.16	0.96	0.75	1.82	1.18	1.05	1.06	0.90	0.75	1.19	1.68	2.44	2.50	2.59	2.44	4.22	4.67	5.18
Repetition	Repetition SD		1.79	1.58	1.03	2.17	1.30	0.88	1.19	1.07	0.76	0.46	1.00	0.24	0.24	0.40	0.34	0.29	0.64	0.77	0.59	1.00	1.55
BW Average	Tester/System Ave SD		1.87	1.59	1.21	2.11	1.46	1.10	1.89	1.16	1.06	0.83	0.70	0.84	1.23	1.87	2.03	1.62	1.58	1.95	3.62	3.98	3.44
DJ	2	1	2.10	2.16	2.48	2.26	0.97	0.86	1.82	1.53	1.04	0.90	0.86	1.00	1.38	1.92	1.87	0.86	1.18	2.38	3.32	3.76	2.93
DJ	2	2	2.40	1.54	1.51	2.57	1.04	1.37	2.16	1.35	1.14	0.75	1.02	0.97	1.38	2.39	1.83	0.86	0.95	1.82	4.02	4.22	3.16
DJ	2	3	5.63	2.49	1.76	2.80	1.17	1.41	0.87	0.90	0.69	0.96	0.74	0.90	1.46	2.35	2.17	1.14	0.93	1.96	3.96	4.70	3.92
Repetition	Repetition SD		1.54	1.96	2.46	2.12	2.34	1.24	0.67	1.28	0.44	0.47	0.37	0.63	0.26	0.41	0.21	0.14	0.61	0.77	0.61	0.50	1.20
DJ Average	Tester/System Ave SD		3.38	2.06	1.92	2.54	1.06	1.21	1.62	1.26	0.96	0.87	0.87	0.96	1.41	2.22	1.96	0.95	1.02	2.05	3.76	4.23	3.34
SC	3	1	2.07	1.14	1.58	2.36	1.38	1.64	1.41	1.15	0.57	1.35	0.50	0.77	1.08	2.28	2.39	2.03	1.98	2.22	2.98	3.34	3.86
SC	3	2	2.56	3.05	2.55	1.01	2.23	1.25	1.20	1.37	1.14	0.88	0.65	0.95	1.35	2.05	2.80	2.50	1.98	1.79	2.29	2.62	2.71
SC	3	3	3.89	2.32	1.54	1.68	1.25	0.79	1.72	1.10	0.65	0.78	0.50	1.04	1.37	1.88	2.25	1.72	1.63	1.81	2.62	2.12	1.86
Repetition	Repetition SD		2.18	1.12	1.13	1.66	2.09	0.61	0.73	0.89	0.74	0.76	0.46	0.54	0.55	0.58	2.48	2.42	1.91	2.21	3.22	3.43	2.54
SC Average	Tester/System Ave SD		2.84	2.17	1.89	1.68	1.62	1.23	1.44	1.21	0.79	1.00	0.55	0.92	1.26	2.07	2.48	2.08	1.86	1.94	2.63	2.69	2.81
SM	4	1	3.53	2.77	1.37	2.88	1.62	1.45	1.04	1.48	0.61	0.86	0.91	1.08	1.31	2.12	2.09	0.96	1.26	2.02	3.57	4.08	3.18
SM	4	2	2.74	1.22	1.63	2.24	1.57	1.16	1.86	1.07	0.63	0.74	0.78	0.45	1.41	2.16	1.78	1.10	1.15	2.16	3.77	4.17	3.19
SM	4	3	3.17	0.92	1.42	0.77	1.48	1.35	2.04	0.77	0.68	0.67	0.84	0.79	1.06	2.05	2.35	0.98	0.90	1.73	3.59	4.16	3.19
Repetition	Repetition SD		1.23	1.65	2.10	2.13	1.97	1.05	0.88	0.69	0.65	0.74	0.53	0.53	0.49	0.19	0.07	0.32	0.20	0.53	0.30	1.03	1.52
SM Average	Tester/System Ave SD		3.15	1.64	1.47	1.96	1.55	1.32	1.65	1.11	0.64	0.76	0.84	0.78	1.26	2.11	2.07	1.01	1.10	1.97	3.65	4.13	3.19
SP	5	1	1.53	2.06	2.39	1.39	1.00	0.82	1.19	1.40	0.40	0.70	0.75	1.09	1.12	2.37	1.80	0.80	1.32	2.32	3.09	3.93	2.96
SP	5	2	2.66	3.02	2.83	2.33	2.09	1.29	1.53	1.32	0.84	0.93	1.03	1.07	1.49	1.89	1.74	0.86	0.95	1.75	3.51	4.03	3.24
SP	5	3	2.03	2.90	2.49	1.83	1.07	1.21	1.45	1.49	1.14	0.42	0.53	1.21	1.28	1.98	1.93	1.63	1.14	2.01	3.83	4.79	4.34
Repetition	Repetition SD		2.08	2.32	2.66	1.85	1.48	1.41	1.19	0.93	0.85	0.54	0.55	0.68	0.34	0.38	0.66	0.65	0.44	0.74	0.56	0.56	1.28
SP Average	Tester/System Ave SD		2.07	2.66	2.57	1.85	1.38	1.11	1.39	1.40	0.79	0.69	0.77	1.13	1.30	2.08	1.82	1.10	1.14	2.03	3.48	4.25	3.51
		Ave SD across All Testers	2.2	2.6	2.6	2.1	1.5	1.2	0.8	0.8	0.6	0.5	0.5	0.4	0.4	0.3	0.4	0.4	0.4	0.4	0.4	0.7	0.9
BW		Ave SD - 1	2.3	2.3	2.4	2.7	1.6	2.1	0.7	0.8	0.5	0.5	0.4	0.3	0.3	0.3	0.3	0.2	0.3	0.4	0.3	0.6	0.8
DJ		Ave SD - 2	2.3	2.3	2.3	1.5	1.4	1.0	0.7	0.7	0.5	0.5	0.4	0.4	0.3	0.3	0.3	0.2	0.3	0.4	0.3	0.3	0.6
SC		Ave SD - 3	1.8	3.6	3.2	2.4	1.3	1.0	1.0	0.9	0.9	0.8	0.6	0.6	0.5	0.5	0.9	0.9	0.8	0.7	1.1	1.5	1.8
SM		Ave SD - 4	2.1	2.4	2.1	1.7	2.3	1.0	0.7	0.6	0.5	0.4	0.4	0.3	0.3	0.3	0.2	0.2	0.3	0.3	0.3	0.4	0.5
SP		Ave SD - 5	2.4	2.4	3.1	2.2	1.2	0.9	0.9	0.9	0.5	0.6	0.5	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.5	0.8