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# 1aAAb3. Straw bale sound insulation: Blowing away the chaff

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Popular opinion states that straw bale walls are good at isolating sound. Cheap load bearing straw bale houses could contribute substantially to low carbon sustainable construction. However, literature on the subject was found to be highly anecdotal. Nine laboratory and field sound insulation test reports were found and two tests were commissioned for this paper. Data was compared to European party wall sound insulation criteria and it was found that straw walls could perform as well as, but sometimes worse than, conventional constructions, due to poor performance at low frequencies. Better performance could help to promote the use of straw bales in multi-unit housing and it was found that adding a plasterboard layer on studs to just one side of a plastered straw bale wall could help it pass all of the criteria reviewed.

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## INTRODUCTION

Materials such as straw, dung and mud have been used for centuries to construct buildings in many different countries and societies. In modern times there has been a widespread move towards the use of brick, cement and concrete as construction materials. Man made materials such as Portland cement and steel consume large amounts of energy in their procurement and manufacture. The use of these to form reinforced concrete or steel framed structures provide a construction technique that can adapt to countless situations, but they are viewed as having negative properties in regards to sustainability and environmental impact.

One material enjoying a renaissance is straw and, from the authors previous interest in the subject it appeared that the general consensus was that straw was not just a good sound insulator but an excellent one, outperforming modern materials by a healthy margin. Until recently most straw bales houses have been detached properties[1], often in rural locations and as a result sound insulation has, up until now, not been a particular hurdle for straw bale builders. There appears to be limited research into the sound insulating properties of straw bale walls and hence it should be quantified, Allowing straw bale constructions to be widely adopted as a mainstream construction technique for cheap, natural and sustainable houses and schools. For this, straw bale walls must be good enough to be used as party walls and must be able to pass commissioning tests where required.

Research has already been carried out into the suitability of straw bale housing for the United Kingdom [2] which concludes that it would meet building regulations. Whether straw can provide sustainable acoustics, identified as important to a low carbon future by the United Kingdom's Institute of Acoustics[3], as well as meeting other sustainability requirements, is the major question posed in this paper.

## AIR BORNE SOUND INSULATION STANDARDS

There are a number of British, International and America standards for the measurement and calculation of air borne sound insulation appropriate for laboratory [4] or in the field [5]. A method to rate airborne sound insulation by a single number method is set out in [6] using reference frequency curves in 1/3 octave band data whether in R, R', $D_{nT}$ format.

The spectrum adaptation terms C and Ctr offer a method of adapting the single number value to take into the account the shape of noise spectra [7]. C spectrum is described as characterizing the difference between the sound levels in the source room and receiving room for pink noise and the Ctr spectrum for road traffic noise. The effect of adding these spectrum adaptation terms to the single number quantities is mainly in penalizing poor low frequency performance of partitions tested especially in the case of Ctr. $D_{nT,w(C\ :Ctr)}$ the values for C and Ctr are normally negative thus reducing the single number weighting value when combined with it .

Sound Transmission class is very similar to $R_w$ and is used in the USA. Laboratory tests similar to ISO 140-3:1995 are performed to the ASTM E90 and then a single number weighting is applied to the results in a similar manner to ISO 717-1:1997 using the ASTM E413. The main difference in the weighting method is that the ASTM method frequency range is 125 Hz - 4 kHz as opposed to the 100 Hz - 3150 Hz range of the ISO standards. The reference curves are identical where they overlap in frequency but are applied in a slightly different way.

Rasmussen and Rindel discuss the wide variety of criteria and descriptors in Europe in Concepts for evaluation of sound insulation of dwellings - from chaos to consensus? [8]. It has been updated with current Northern Ireland and Scottish legislative requirements, as shown in Table 1.

| Country | Descriptor[1] | Multi-storey housing Req. (dB) | Row housing Req. (dB) |
|---|---|---|---|
| Austria AUT | $D_{nT,w}$ | ≥55 | ≥60 |
| Belgium BEL | $D_{nT,w}$ | ≥54 | ≥58 |
| Czech Republic CZE | $R'w$ | ≥52 | ≥57 |
| Denmark DNK | $R'w$ | ≥55 | ≥55 |
| England and Wales | $D_{nT,w}+ C_{tr}$ | ≥45 | ≥45 |
| Estonia EST | $R'w$ | ≥55 | ≥55 |
| Finland FIN | $R'w$ | ≥55 | ≥55 |
| France FRA | $D_{nT,w}+ C$ | ≥53 | ≥53 |
| Germany[7] DEU | $R'w$ | ≥53[5] | ≥57 |
| Hungary HUN | $R'w + C$ | ≥51 | ≥56 |
| Iceland ISL | $R'w$[3] | ≥52[6] | ≥55 |
| Ireland IRL | $D_{nT,w}$ | ≥53[5] | ≥53 |
| Italy ITA | $R'w$ | ≥50 | ≥50 |
| Latvia LVA | $R'w$ | ≥54 | ≥54 |
| Lithuania LTU | $D_{nT,w}$ or $R'w$ | ≥55 | ≥55 |
| Netherlands NLD | $I_{lu;k}$[2] | ≥0 | ≥0 |
| Northern Ireland | $D_{nT,w}$ | ≥53 | ≥53 |
| Norway NOR | $R'w$[4] | ≥55[4] | ≥55[4] |
| Poland POL | $R'w + C$ | ≥50[5] | ≥52[6] |
| Portugal[7] PRT | $D_{n,w}$ | ≥50 | ≥50 |
| Scotland | $D_{nT,w}$ | ≥56 | ≥56 |
| Slovakia SVK | $R'w$ | ≥52 | ≥52 |
| Slovenia SVN | $R'w$ | ≥52 | ≥52 |
| Spain ESP | $D_{nT,w}+ C_{100\text{-}5000}$ | ≥50 | ≥50 |
| Sweden SWE | $R'w + C_{50\text{-}3150}$ | ≥53 | ≥53 |
| Switzerland CHE | $D_{nT,w}+ C$ | ≥52[8] | ≥55 |

Table 1. European sound insulation descriptors and criteria.

## REVIEW OF STRAW BALE SOUND INSULATION TESTS

An extensive review of print and electronic media revealed an overwhelmingly a primitive view of the notion of super sound insulation performance but with little empirical evidence. Much of the literature failed to provide sources for claims of good sound insulation and when they were provided they often led back to experiments that were of an amateur nature or intended as rough assessments of performance.

The search revealed four laboratory airborne sound insulation tests on straw bale walls (Eindhoven [9], FASBA [10], GraT [11] and BRE-Modcell [12]) and five field sound insulation tests (DELTA [13], Genesis Centre [14], Waddington [15], Martin [16]and MACH-Modcell [17]); all nine of these tests were room to room except for the Modcell test which was for a facade wall. The tests are for various construction types and thicknesses and the results are given in several different descriptors. All of the data from the nine tests above will ,where possible, be converted to the Approved Document E standard of $D_{nT,w}$. A full literature review is available [18].

## STRAW BALE SOUND INSULATION TESTS

Two field airborne sound insulation tests were carried out to ISO 140-4:1998 on the houses at Waddington (see Figure 1) with one for the ground floor party wall and the other for the first floor. At Ralegh's Cross (see Figure 2) just one set of tests were performed for the ground floor. The equipment used for the tests consisted of a Bruel and Kjaer Type 2250 sound analyzer with 1/3rd octave and reverberation software and a Lookline D301 omni-directional loudspeaker with internal power amplifier and signal generator (Figure 3).


Figure 1. Waddington Semi-detached House. Figure 2. Ralegh's Cross Semi-Detached House

The party wall bales were approximately 450mm wide with a 30mm coating of lime plaster on each side. Both walls failed the commercial tests and those carried out for this project. A further set of commercial tests were undertaken after a stud wall had been built on one side of the party walls in one of the houses. This consisted of two layers of high density 12.5mm plasterboard mounted on timber studs with 755mm of Isowool insulation behind and a minimum 10mm air-gap. In this instance the results greatly exceeded the criteria in Approved Document E at the expense of floor area in one of the houses, see Figure 5.

For Ralegh's Cross it was discovered that the plaster work on the party wall between the two kitchen areas had only received a rough coat, so was not complete. In addition, 4 apertures were apparent and only two 18mm plywood boards were available to block them downstairs. These factors meant that full compliance with ISO 140-4:1998 was not possible but it was felt that a test was still worth doing as it would still provide data which could possibly be compared with a full test once the housing is completed at a later date, see Figure 5.


Figure 3. Equipment in source room - Ralegh's Cross. Figure 4. Viewing Panel in Ralegh's Cross

At Ralegh's Cross viewing panels were placed in the party wall directly opposite each other (Figure 4). Although the viewing panels were located in the hallway away from day to day areas of the house and not yet finished with their glass, when pink noise was played in the source room at maximum volume it was apparent that the noise increased by the viewing panel in the receiver room. This is a design feature that would warrant re-measurement on the completion of the house and should be avoided in the future, as it compromises performance.

## Measurement Problems

Both homes were not ready for testing on the specified day. Ralegh's Cross also contained building materials which could also have influenced the measurements. Additionally, the house had all of its windows open and the authors were told by a member of staff at the Inn that this was to let it dry out; whether this was because the plastering had been completed in the recent months or there had been a damp problem was not clear. When attempting to close the windows it was found that many of them were stiff and one or two could not be closed properly and had small air gaps. The front doors had similar problems. It was not clear whether these problems were caused by damp, by the building shifting or by poor installation but if may be a contributory factor in the tests.

## LABORATORY AND FIELD TEST COMPARISONS

All of the 450mm straw bale field sound insulation tests are shown in Figure 5. For clarity, the 1/3rd octave $D_{nT}$ results for Waddington were arithmetically averaged as were those for the Genesis tests (ADE method). Apart from the MACH (Modcell) tests there seems to be a shared coincident dip at around 125 Hz to 200 Hz. The MACH (Modcell) results seem to follow a very different pattern from the rest of the tests with the best low frequency performance at 100 Hz to 125 Hz but with worse performance even than Ralegh's Cross further up the frequency range. The graph is not entirely correct as the Y-axis is labelled $D_{nT}$ but of course the MACH (Modcell) tests were to a different standard (ISO 140-5:1998) and use the R'45º descriptor so cannot be properly compared; the data has been included however as the shape of the curve still shows the same inter-frequency relations. Poor sealing of the window may have compromised the MACH (Modcell) test.

| Test | DELTA | | Genesis | | | | MACH | Waddington | | | | | | Martin | | Ralegh's Cross |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wall | 1 | 2 | 1a | 1b | 2a | 2b | 1 | GF1 | FF1 | GF2 | FF2 | GF3 | FF3 | GF | FF | 1 |
| AUT | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✗ |
| BEL | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✗ |
| CZE | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✗ |
| DNK | ✗ | ✗ | ✓ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✗ |
| EST | ✗ | ✗ | ✓ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✗ |
| FIN | ✗ | ✗ | ✓ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✗ |
| FRA | ✗ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✗ |
| DEU | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✗ |
| HUN | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✗ |
| ISL | ✗ | ✗ | ✓ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✗ |
| IRL | ✗ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✗ |
| ITA | ✗ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✓ | ✓ | ✗ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ |
| LVA | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✗ |
| LTU | ✗ | ✗ | ✓ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✗ |
| NLD | ✗ | ✗ | ✓ | ✗ | ✗ | ✗ | ✗ | ✓ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✗ |
| NOR | ✗ | ✗ | ✓ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✗ |
| POL | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✗ |
| PRT | ✗ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ |
| SVK | ✗ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✗ |
| SVN | ✗ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✗ |
| ESP | ✗ | ✓ | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✗ |
| SWE | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✗ |
| CHE | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✗ |

Table 2 European criteria compliance

Both the laboratory and field sound insulation tests exhibit a wide range of results. Nearly all partitions exhibit fairly poor sound insulation at low frequencies usually caused by a resonance or coincident dip between 125 Hz and 315 Hz. The only partitions with good low frequency sound insulation were the GrAT, Martin and final Waddington partitions. These partitions all feature a composite design of straw bale with an added panel element. Table 2 reanalyses the data for the purposes of European compliance.

## CONCLUSIONS

It was found that most types of plastered straw bale wall would either not meet the criteria or only exceeded it by small amounts. It has been established that a straw bale wall with plaster one side and a double layer plasterboard partition the other side can satisfy all European sound insulation criteria for dividing walls between dwellings. However, the use of plasterboard and extra labour needed for this reduces the sustainability of the walls as well as increasing the width of a wall which some might already find unacceptable, especially in parts of the United Kingdom where land is at a very high premium and space therefore limited by cost.

To summarize the project: the idea that straw is a super sound insulator is not apparent from the evidence. Reasons for this belief may be down to the lack of multi-unit housing using straw bales to date. Improvements to the performance will need additional layers of material and careful flanking design. A serious programme of research is needed to improve sound insulation and if directed at Nebraska style construction, the cheapest technique, could help push straw bale construction as a mainstream technique for house building in the UK and Europe.

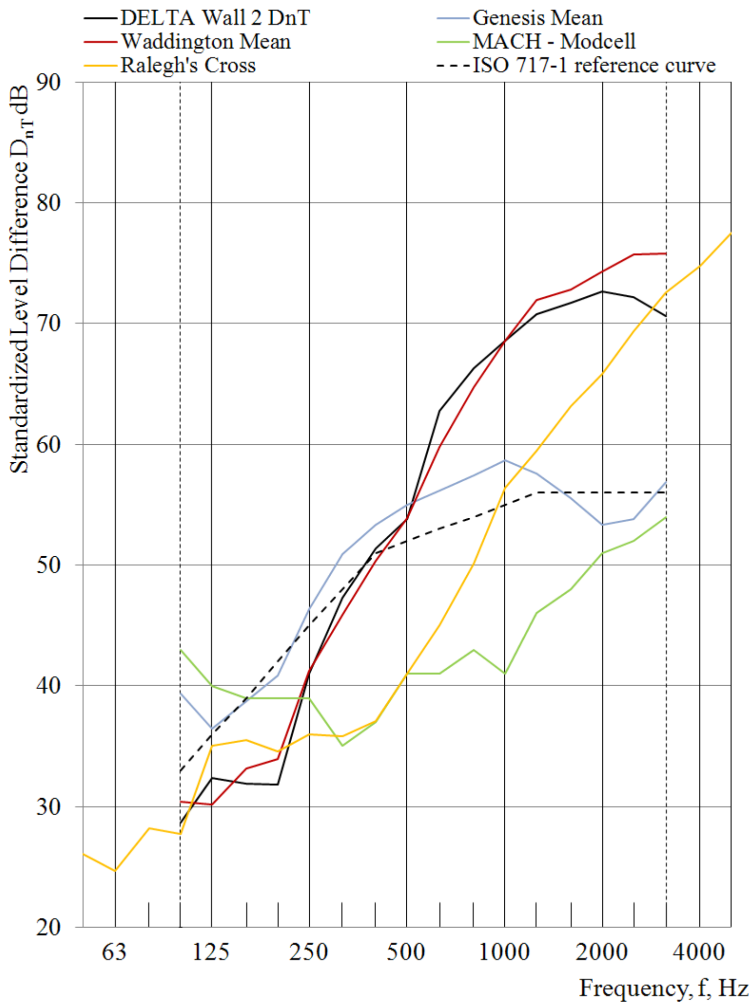


Figure 5 Comparison of all 450mmm straw bale wall sound insulation tests

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