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Research Department Report

A MODULAR WIDEBAND SOUND ABSORBER

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Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

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Summary

The absorption coefficients were measured of various depths of RW2 grade Rockwool laid directly on the floor of the ISO-Standard reverberation room at BBC Research Department. The Rockwool was very effective as a wideband sound absorber.

A new absorber was designed and tested, having the dimensions of existing BBC type A modular absorbers and containing RW2 Rockwool. The new absorber has a smoother absorption coefficient curve, a less complicated construction and weighs less than the existing BBC wideband absorber (type A8/A9). It has been named type A11 and has an equivalent performance to that of BBC type A2 and A3 absorbers combined. It complements, very well, the performance of the A10 very low frequency absorber, described in a companion Report (BBC RD No. 1992/10).

Index terms: *Sound; absorbers*

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1. INTRODUCTION

Initial measurements of the absorption coefficients of different thicknesses of mineral wool laid directly on the floor of an ISO-Standard reverberation room showed that it was a very effective wideband absorber. The purpose of the work described in this Report was to determine whether an effective modular wideband absorber could be constructed from a box of dimensions 580 × 580 × 183.5 mm, containing mineral wool.

Possible advantages of such a design over that of the existing BBC type A9 absorber are:

1. A smoother absorption coefficient curve, covering the same frequency range.
2. A less complicated construction, which should make it cheaper.
3. The absorber should weigh less. This would reduce the loading on walls on which it is mounted, which may be significant when the absorber is to be mounted on lightweight partitions.

2. INITIAL MEASUREMENTS

The absorption coefficients of different thicknesses of RW2 grade Rockwool, with the edges enclosed by a reflective chipboard frame, were measured in the ISO-Standard reverberation room at BBC Research Department. The results of these measurements are shown in Fig. 1. The curves are fairly erratic at lower frequencies. Also, for sample depths of 180 mm and 270 mm, the absorption coefficients below 1 kHz exceed a value of 1.0. This occurs because of diffraction of sound at the edges of the sample[1].

The absorption coefficient of a porous absorber over a reflecting surface can be predicted from flow resistivity measurements[2, 3]. Fig. 2 shows the theoretical absorption coefficients of various depths of a porous absorber, calculated assuming a flow resistivity of 6000 MKS rayls/m. This value of flow resistivity is typical of that measured for mineral wools with similar densities to that of RW2 grade Rockwool. Although the value used is only an estimate of the flow resistivity for RW2 Rockwool, the shapes of the absorption coefficient curves do not depend strongly upon the flow resistivity value.

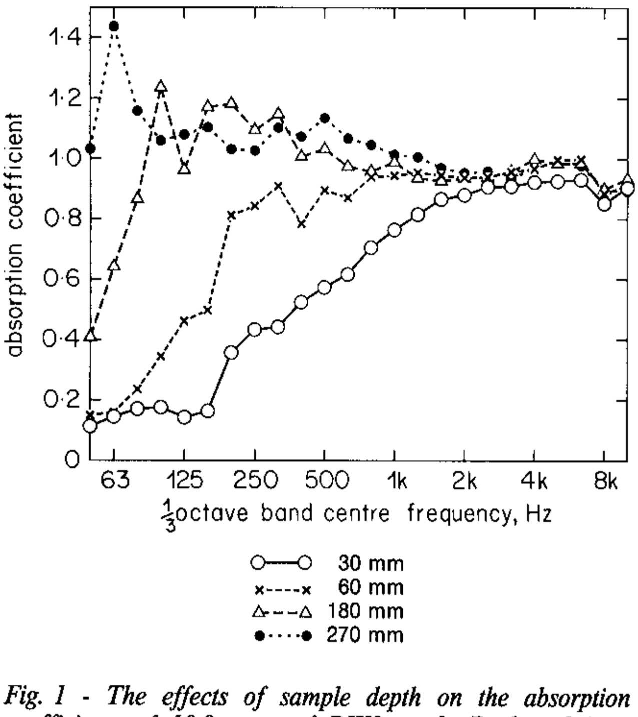


Fig. 1 - The effects of sample depth on the absorption coefficients of 10.8 sq. m of RW2 grade Rockwool in a chipboard frame.

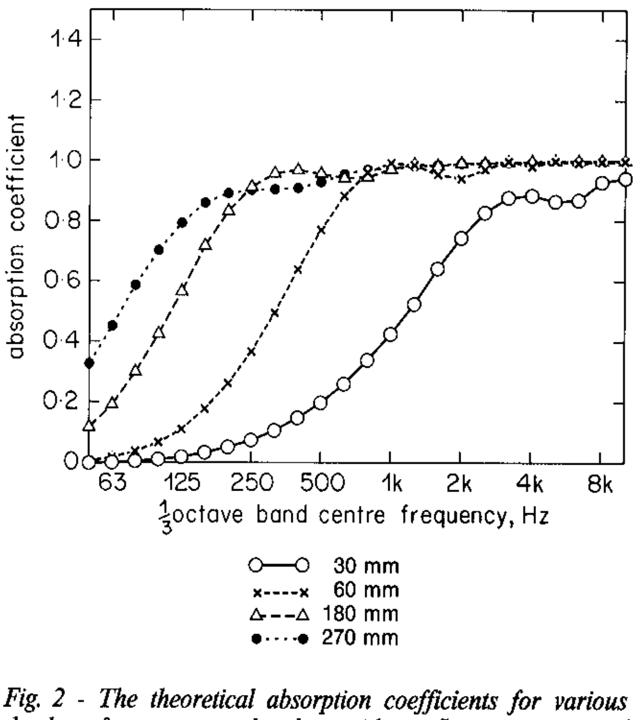


Fig. 2 - The theoretical absorption coefficients for various depths of a porous absorber with a flow resistivity of 6000 MKS rayls/m.

Ref. 2 includes a similar reverberation room measurement of the absorption of a Rockwool material compared with a theoretical prediction of its absorption from a flow resistivity measurement. As for the curves of Figs. 1 and 2, the roll-off at lower frequencies for the reverberation room measurement was approximately one octave lower than for the theoretical prediction. No comment was made in the reference on the possible reasons for the discrepancy. Other measurements[4] have also shown porous absorption at frequencies lower than predicted by theory.

The reason for this extended absorption at lower frequencies is not known. One possible mechanism involves the layer of Rockwool behaving as a membrane absorber. Further studies, beyond the scope of the work described in this Report, would be necessary to determine whether membrane absorption was the reason for the extended absorption at lower frequencies. (An optical interferometer could be used to measure the motion of the surface of the Rockwool when excited by a sound field, to determine whether a membrane resonance was occurring.)

It is also possible that the theoretical predictions differ from the practical measurements because the theory assumes normal incidence of sound. In the reverberation room, sound is randomly incident upon the absorber. For oblique incidence of sound upon a porous absorber, the measured absorption coefficient is greater than that measured for normal incidence[5]. This is because, for oblique incidence, the sound travels a greater distance through the absorber before emerging again and will, therefore, be absorbed to a greater extent. For an isotropic porous absorber, the absorption for oblique incidence is greater than the absorption for normal incidence. Layered fibrous materials such as Rockwools are anisotropic. This will have further implications on the directional properties of the absorbent material. In the reverberation room, the overall absorption coefficient for all incidence angles is measured, which should, therefore, extend to lower frequencies than for normal incidence.

Fig. 3 shows a normal incidence measurement of the absorption coefficient of a patch of RW2 grade Rockwool of size 1.2 m × 1.2 m × 80 mm thick over a reflective surface. The measurement was made in a free-field room using a point sound source and a closely matched microphone pair, as detailed elsewhere[6, 7]. The results are not reliable for low values of absorption coefficient, or at lower frequencies when the wavelength of the sound in air is large compared with the dimensions of the sample. However, there is very good agreeement, above 315 Hz, between the normal incidence measurement and that predicted for a porous absorber with a flow

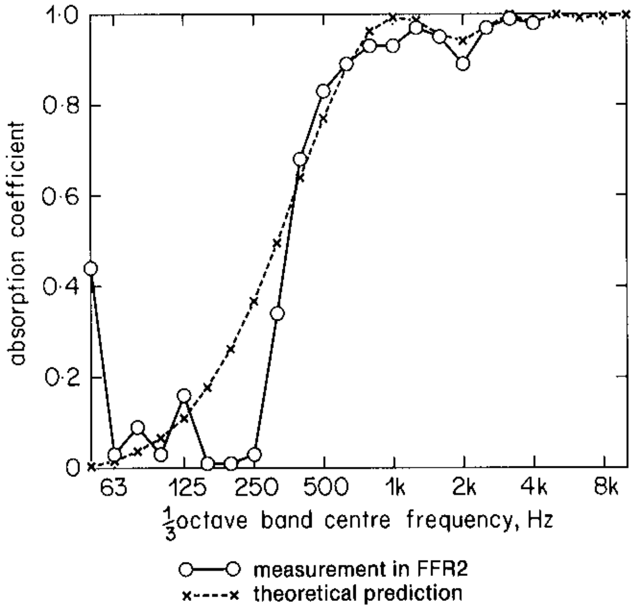


Fig. 3 - The absorption coefficients, at normal incidence, of 80 mm thick RW2 grade Rockwool.

resistivity of 6000 MKS rayls/m. In particular, there is no discrepancy between the two curves in the frequency below which the absorption tails off. The normal incidence absorption coefficient measurement agrees with the theoretical results which were derived assuming normal incidence of sound. Consequently, the hypothesis is supported: that the extended low frequency absorption for the measurement in the ISO-Standard reverberation room is linked with the fact that the sound is randomly incident upon the Rockwool.

To verify that the extended absorption of RW2 Rockwool at lower frequencies was not some peculiar artefact of this particular material, the absorption coefficient of 100 mm thick 'Supawrap' (glass fibre loft insulation material) in a chipboard frame was measured in the ISO-Standard reverberation room at BBC Research Department. The results are shown in Fig. 4. Although there is a small difference in the overall absorption between the 100 mm thick 'Supawrap' and the 80 mm thick RW2 Rockwool, the low frequency roll-off occurs at approximately the same frequency for the two different absorbers. In both cases, the roll-off at low frequencies occurs approximately one octave lower than expected from theory. This shows that the extended absorption is not some peculiar artefact of RW2 Rockwool alone.

Whatever the reason for this extended low frequency absorption, RW2 Rockwool is very effective as a wideband absorber. Fig. 5 shows the absorption coefficient of 180 mm depth of RW2 Rockwool compared with that for the existing BBC design of wideband absorber (type A9[8]) of depth 183.5 mm.

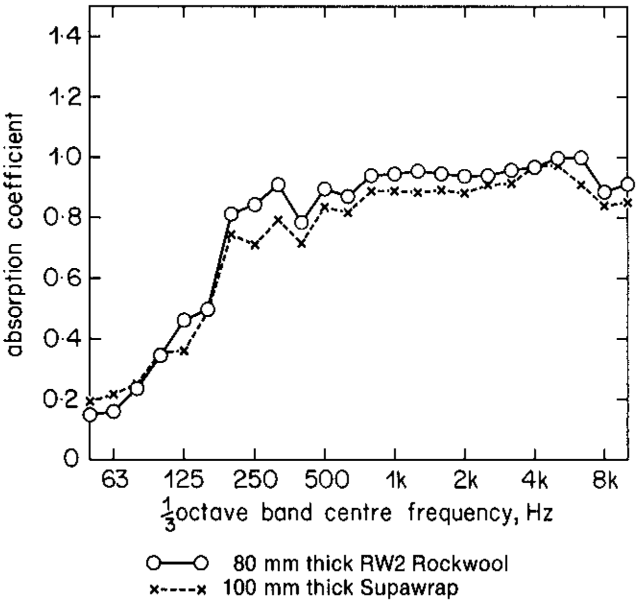


Fig. 4 - The measured absorption coefficients of 10.8 sq.m of different porous absorbers in a chipboard frame.

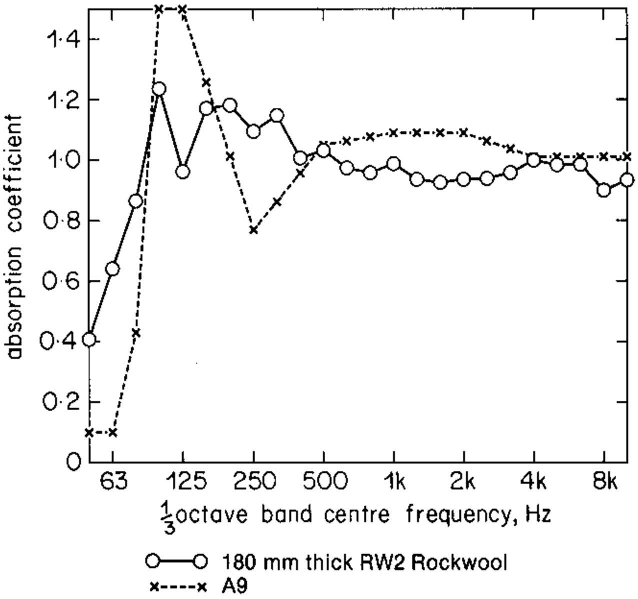


Fig. 5 - A comparison between the absorption coefficients of 180 mm thick RW2 Rockwool and BBC type A9 modular absorbers.

The A9 absorber has:

1. A lower absorption in the range 50 Hz to 80 Hz.
2. An excess of absorption between 100 Hz and 125 Hz.
3. A dip in absorption centred on 250 Hz.

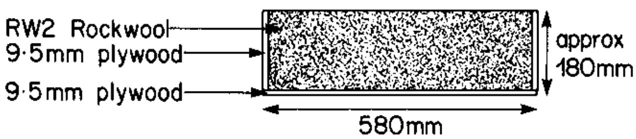
Of these three factors, the dip at 250 Hz is the most undesirable.

It was considered worthwhile to try to design a wideband modular absorber containing mineral wool. The wideband absorber should have an absorption coefficient curve of similar shape to that of a patch of RW2 Rockwool laid directly on the floor of the ISO-Standard reverberation room.

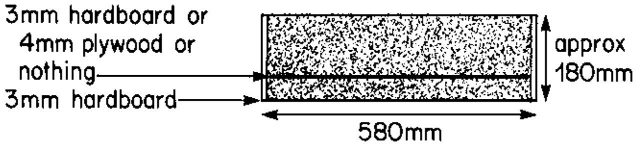
3. BOXES WITH 9.5 mm THICK PLYWOOD BACKS

In conjunction with other studies on the development of a new type of low frequency absorber[9], the absorption coefficient was measured of 28 modular boxes containing 175 mm depth of RW2 Rockwool (100 mm and 75 mm thick slabs cut to a size of 560 mm × 560 mm), in the ISO-Standard reverberation room. The modular boxes were of size 580 × 580 × 180 mm, with an open front and 9.5 mm thick plywood sides and back (see Fig. 6(a)).

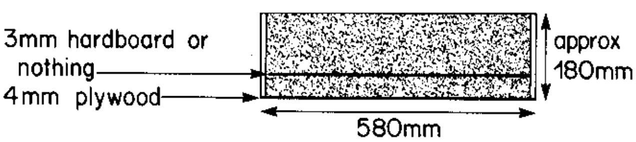
Fig. 7 shows the absorption coefficient of the modular boxes compared with that of the Rockwool in the chipboard frame. Below 125 Hz, the absorption of the boxes is significantly lower than of the sample in the frame. The sides of the boxes are relatively reflective and they subdivide the sample. This division will restrict transverse motion of sound through the absorber, which will reduce the absorption at lower frequencies. Subdividing the Rockwool with reflective dividers in this manner results in a roll-off at low frequencies which is closer to that for the normal incidence absorption coefficient of Rockwool predicted



(a) 9.5 mm plywood back.



(b) 3 mm hardboard back.



(c) 4 mm plywood back

Fig. 6 - Sections through the absorbers tested.

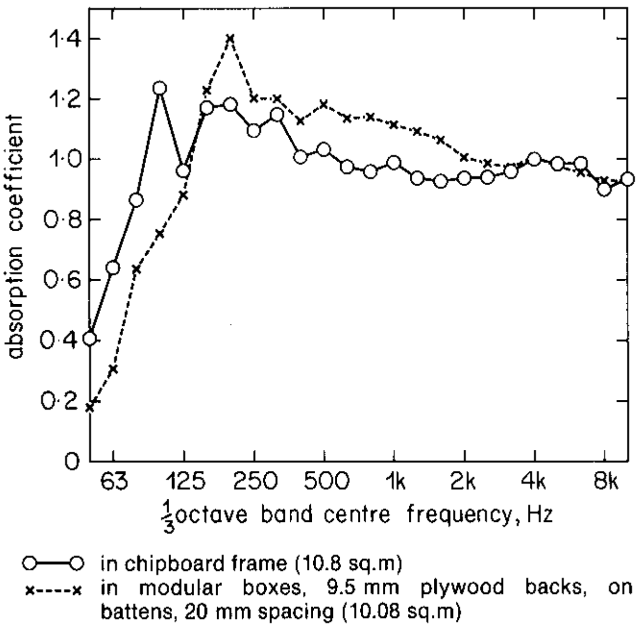


Fig. 7 - The absorption coefficient of 180 mm thick RW2 Rockwool.

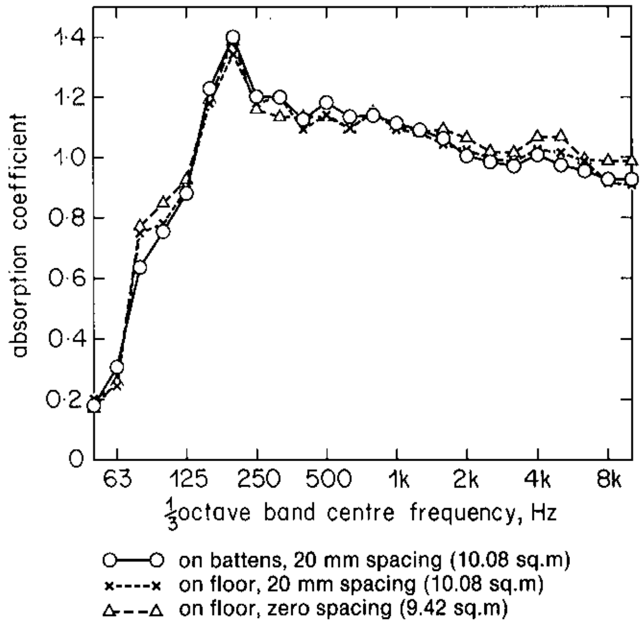


Fig. 8 - The effects of mounting conditions on the absorption coefficient of 9.5 mm plywood-backed modular absorbers containing RW2 Rockwool.

from its flow resistivity. For the modular boxes, the peak at 200 Hz is probably linked with a resonance of the 9.5 mm back panel. Between 160 Hz and 2.5 kHz, the absorption of the boxes is higher than of the Rockwool in the frame. This difference was probably a result of the samples of Rockwool for the two tests being from different batches (the Rockwool in the frame was several years old, the Rockwool in the boxes was new).

In studios, BBC modular absorbers would usually be spaced 20 mm apart and would be mounted on timber battens. For most measurements in the ISO-Standard reverberation room, therefore, it is normal to mount the modular absorbers in a similar manner. To determine whether the mounting conditions affected the absorption of the boxes, two additional measurements were made. For one measurement, the boxes were laid directly on the floor of the reverberation room, rather than on battens; for the other measurement, there was zero spacing between the boxes. The results are shown in Fig. 8. There is, perhaps, a slight increase in absorption between 80 Hz and 100 Hz on rejoining the sample, although the differences between the curves are generally insignificant.

As an aside, Fig. 9 shows the absorption of the zero-spaced, floor mounted absorbers with a 0.14 mm thick polythene cover. The impervious membrane severely curtails the high frequency absorption of the porous absorber. This is why polythene covers for absorbers should be avoided, even when they are to be used in an outside environment[8].

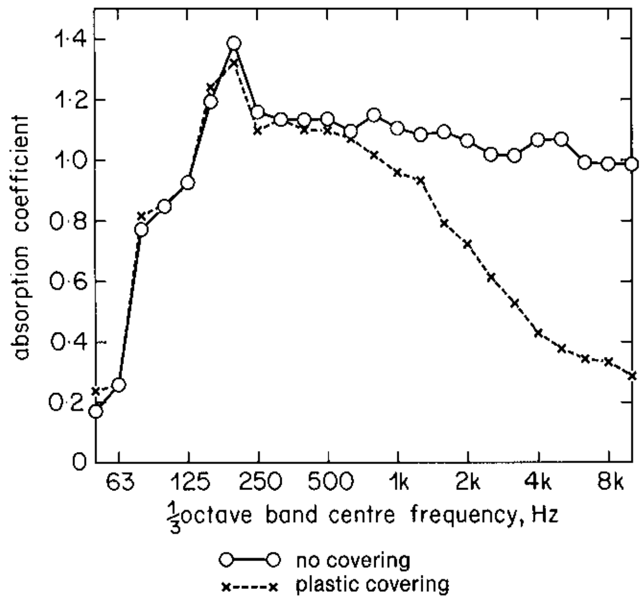


Fig. 9 - The effects of the covering material on the absorption coefficient of 9.42 sq.m of close-spaced, 9.5 mm plywood-backed modular absorbers containing RW2 Rockwool.

4. BOXES WITH 3 mm THICK HARDBOARD BACKS

4.1 Initial reverberation room measurements

The boxes with 9.5 mm plywood backs (Fig. 6(a)) were not considered to be ideal wideband absorbers. Additional absorption at 100 Hz and 125 Hz would be desirable, as would a reduction of the peak in absorption at 200 Hz. It was possible that the absorption could be extended to lower frequencies by the use of a different membrane absorption. The fairly rigid back panel could be replaced by a more absorbent panel, which would be damped by the presence of the Rockwool. Unperforated 3 mm thick hardboard was selected as an alternative back panel.

Thirty modular absorbers with 3 mm hardboard backs were constructed. A cross-section through the absorber is shown in Fig. 6(b)). Additional absorbent panels (either 3 mm hardboard or 4 mm plywood, with dimensions 560 mm × 560 mm) were also prepared for fine-tuning of the absorbent properties of the boxes. These panels could be inserted, at varying depths, between the layers of Rockwool in the boxes. The panels were not restrained at the edges of the boxes.

Fig. 10 shows the absorption coefficient of the Rockwool boxes with 3 mm hardboard backs compared with that of the boxes with 9.5 mm plywood backs (with no infill panels installed in both cases). The differences between the two curves, below 100 Hz and above 200 Hz are insignificant. As required, the boxes with hardboard backs have an increased absorption at 100 Hz and a decreased absorption at 200 Hz. The disadvantage of the box with the 3 mm hardboard back is that its absorption curve has a pronounced dip at 125 Hz.

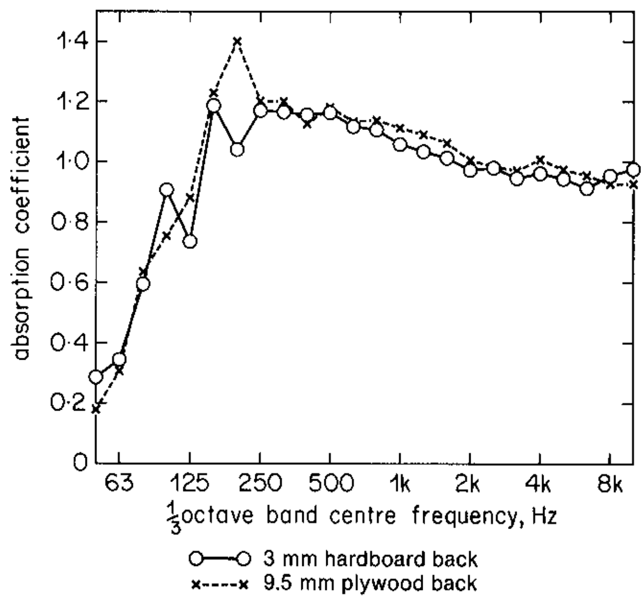


Fig. 10 - The effects of the material used for the back of the modular box on the absorption coefficient of the absorber containing RW2 Rockwool.

4.2 Duct measurements

Reverberation room measurements of absorption coefficients require large areas of sample (typically 10 - 12 m^2). A method exists for the measurement of the absorption of a single modular absorber, based on a standing-wave duct[9], which greatly reduces the time required for the testing and development of the design of an absorber. For an absorber with face dimensions of 0.58 m × 0.58 m, the upper frequency limit for reliable measurements is just over 200 Hz, when using this method. Results have to be interpreted with care because the absorption coefficients measured are for normal incidence of sound.

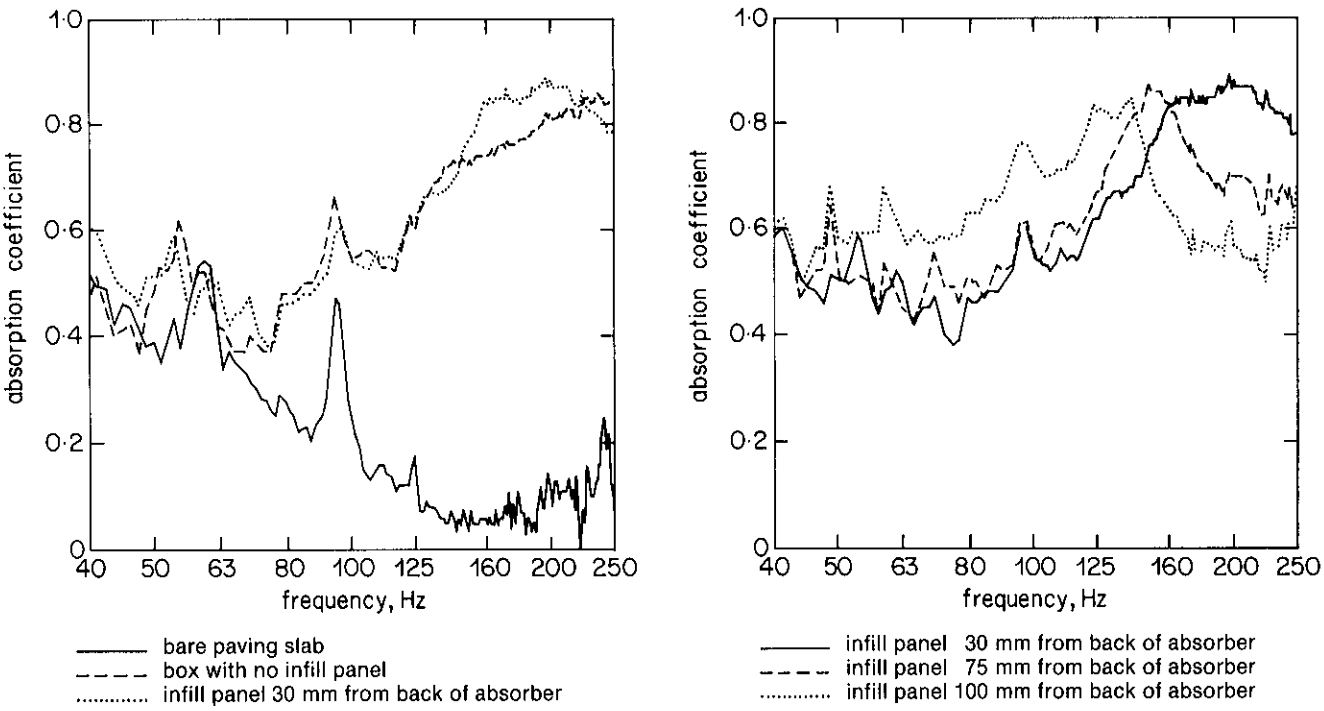
In an attempt to alter the shape, at lower frequencies, of the absorption coefficient curve for the box with the 3 mm hardboard back, a 3 mm thick hardboard infill panel was installed at various depths in the Rockwool (Fig. 6(b)). Duct measurements were performed on a single absorber for each position of the infill panel. Results are shown in Figs. 11(a) and 11(b). The modular absorber was mounted on timber battens, which spaced the absorber 20 mm from a relatively reflective concrete paving slab. The absorption coefficient of the bare paving slab is also shown.

As the distance between the infill panel and the back panel was increased, the peak in absorption in the 125 - 250 Hz region shifted to a lower frequency and the peak narrowed. The results of Figs. 10 and 11 indicated that the absorption coefficient of the modular absorber at 125 Hz, as measured in the ISO-Standard reverberation room, might have been increased by the installation of an infill panel.

4.3 Further reverberation room measurements

Further reverberation room measurements were made of the absorption of the Rockwool absorber box, with a 3 mm hardboard infill panel installed at different depths. The results are shown in Fig. 12. The position of the infill panel had a relatively small effect on the absorption curves above 1 kHz. When the infill panel was 100 mm from the back panel, the absorption coefficient was generally lower than for all the other panel depths, up to a frequency of 1 kHz.

At 100 Hz, the absorption increased slightly as the panel was moved away from the back of the box (except for the 100 mm distance). An additional damped membrane resonance was probably the reason for this extra absorption. Between 125 Hz and 1 kHz, the absorption decreased as the panel was moved



(a) First set of measurements.

(b) Second set of measurements.

Fig. 11 - Standing wave duct measurements on an absorber with an infill panel.

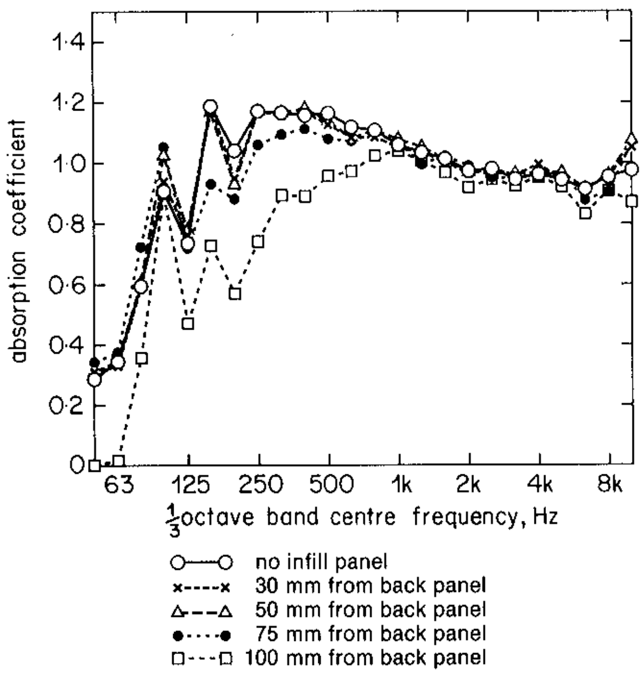


Fig. 12 - The effects of the position of a 3 mm hardboard infill panel on the absorption coefficient of 10.8 sq.m of 3 mm hardboard-backed modular absorbers containing RW2 Rockwool.

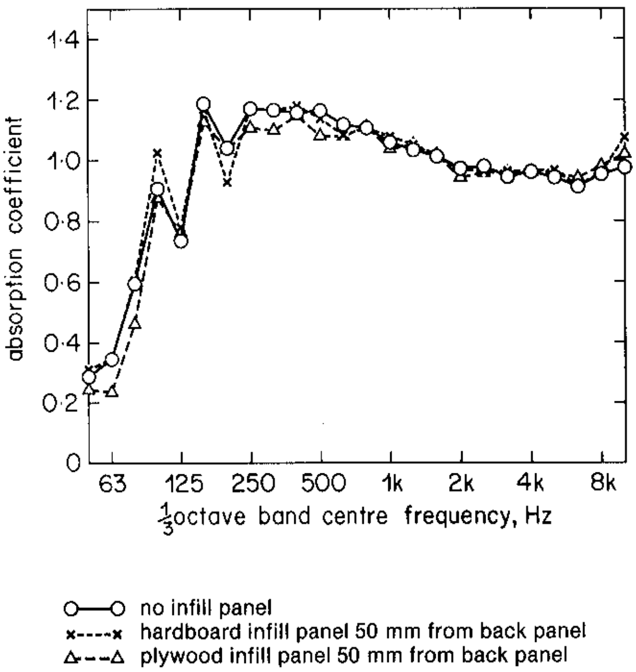


Fig. 13 - The effects of the type of infill panel on the absorption coefficient of 10.8 sq.m of 3 mm hardboard-backed modular absorbers containing RW2 Rockwool.

away from the back of the box. This was probably because the panel acts as a partial reflector to sound at these frequencies, which reduces the absorption by the Rockwool behind the panel. The shape of the absorption coefficient curve was not particularly improved by the installation of the infill panel, at any depth. For this type of absorber, no close link was observed between the duct measurements and the reverberation room measurements, so no further duct measurements were made.

An accelerometer (B & K type 4393) and an electromagnetic shaker were used to measure the resonant frequencies of different sheet materials when installed as infill panels. The resonant frequency of 4 mm thick plywood was higher than that of 3 mm hardboard. Therefore, 4 mm plywood infill panels were installed in the Rockwool boxes in place of the hardboard infill panels, in a single position 50 mm from the back panel. The results are shown in Fig. 13. Two other curves are also shown; one for the Rockwool box with a 3 mm hardboard infill panel 50 mm from the back panel, and the other for the box with no infill panel. The differences between the three curves are relatively small, although the box with the plywood infill panel has the smoothest absorption curve.

5. BOXES WITH 4 mm THICK PLYWOOD BACKS

Although the absorption coefficient curve of the box containing the 4 mm thick plywood infill panel (Fig. 13) was reasonably smooth, the dip at 125 Hz was still too deep. Further experiments with an accelerometer and an electromagnetic shaker indicated that a box with a 4 mm plywood back might have been more appropriate. Therefore, the 3 mm thick hardboard backs were replaced by 4 mm plywood backs, as shown in Fig. 6(c). (The 4 mm plywood panels were fitted on one side of the box before removing the 3 mm hardboard panels from the other side of the box. With both panels in place, the box behaves as a low-frequency absorber, whose characteristics are described in the Appendix.) The results of the absorption coefficient measurements are shown in Fig. 14. The absorption coefficient curve for the box with a 4 mm plywood back is smoother than that for the box with the 3 mm hardboard back. A measurement was also made with a 3 mm thick hardboard infill panel installed 50 mm from the back panel. The absorption coefficient curve was less smooth for this absorber than for the absorber with no infill panel installed.

In Fig. 15, the absorption coefficient curve for the box containing RW2 Rockwool, with a 4 mm plywood back and no infill panel, is compared with those of existing BBC absorber designs. The new absorber performs as well as the A2 at lower frequencies and as well as the A3 at higher frequencies. It has a smoother absorption coefficient curve than that of the A9 wideband absorber. It also complements well the absorption coefficient of the A10 very low frequency absorber.

The new absorber could be covered with fabric and chicken wire to give a decorative, protective finish, as in A1 or A9 absorbers. However, it would

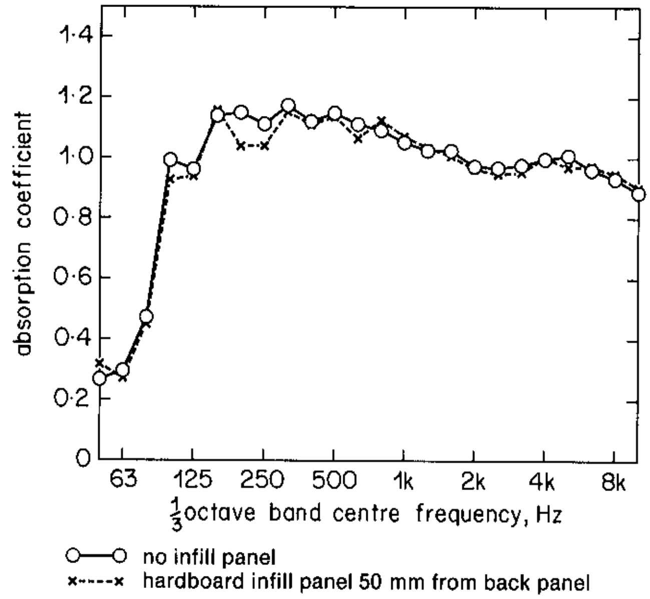


Fig. 14 - The effects of a 3 mm hardboard infill panel on the absorption coefficient of 10.8 sq.m of 4 mm plywood-backed modular absorbers containing RW2 Rockwool.

be desirable to have the option of fitting a 20% perforated hardboard front panel, as in A3 or A8 absorbers. Therefore the absorption coefficient was measured of a small sample of the Rockwool boxes with 4 mm plywood backs and 20% perforated hardboard front panels (only 23 perforated front panels were available). The absorption coefficient was also measured of 23 of the Rockwool boxes without front panels, because the measured absorption coefficient depends upon the sample area[10].

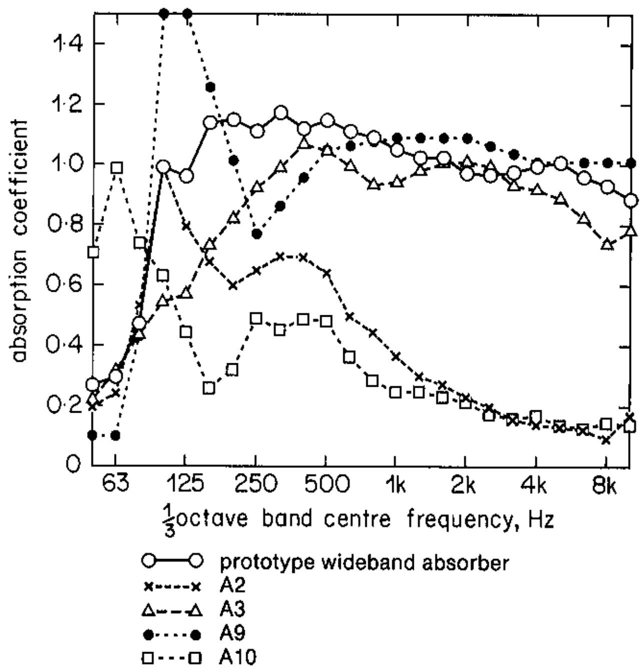


Fig. 15 - Various modular absorbers.

The effects of the perforated hardboard front covering are shown in Fig. 16. The perforated front panels produce a roll-off in high frequency absorption that is consistent with expectations. The differences observed are comparable with those between the absorption of A1 absorbers and the absorption of A3 absorbers. A Rockwool-filled box with a fabric and chicken wire facing would be appropriate in areas where A1 or A9 absorbers would usually be used (mainly television studios). The Rockwool box with a 20% perforated hardboard covering would be appropriate in areas where A3 or A8 absorbers would usually be used (mainly radio studios).

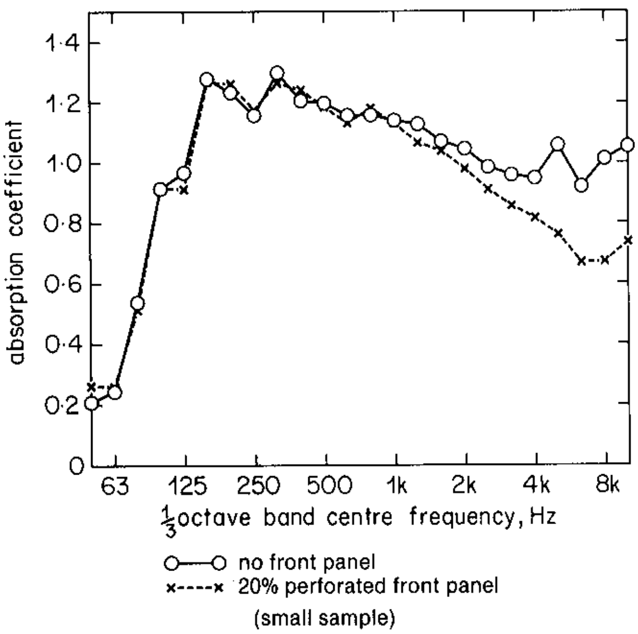


Fig. 16 - The effects of a perforated hardboard front panel on the absorption coefficient of a 4 mm plywood-backed modular absorber containing RW2 Rockwool.

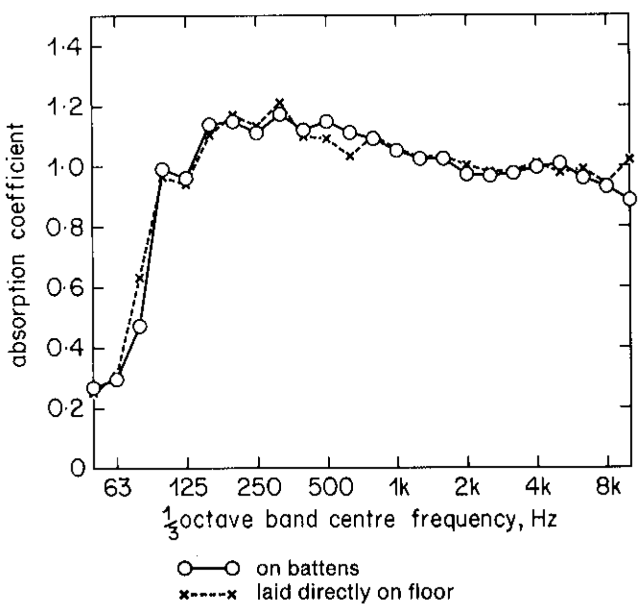


Fig. 17 - The effects of mounting conditions on the absorption coefficient of a 4 mm plywood-backed modular absorber containing RW2 Rockwool.

It was necessary to determine whether mounting the Rockwool absorbers directly on room surfaces, rather than on battens, would affect the absorption by the back panel. Fig. 17 shows the absorption of the Rockwool boxes mounted on battens compared with the absorption of the boxes laid directly on the floor. The differences between the curves are relatively small, which shows that the battens are not necessary for the back panel to absorb. At low frequencies, the 20 mm airspace, provided by the battens, may couple the back panel to the floor to a similar extent to that of the very small airspace, produced when the boxes were laid directly on the floor.

6. CONCLUSIONS

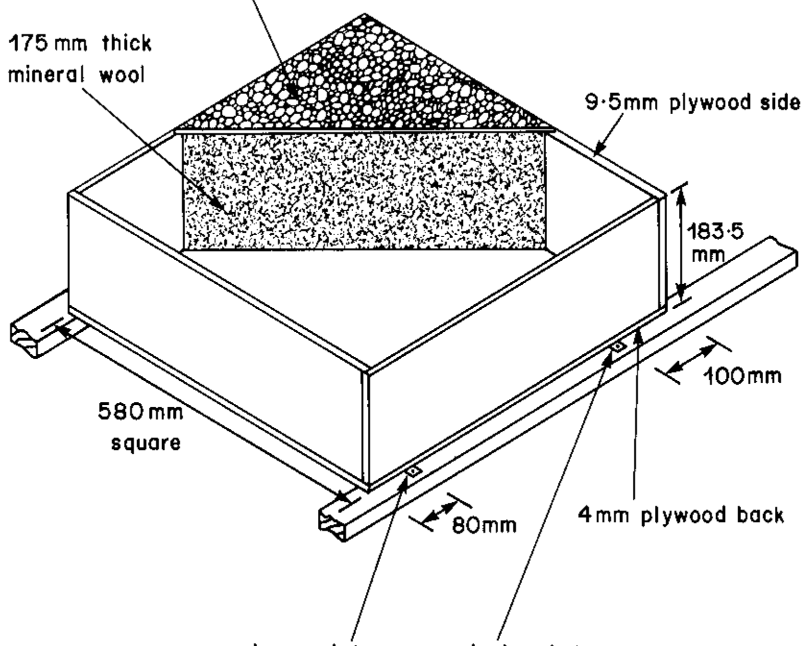
The absorption of RW2 grade Rockwool, laid directly on the floor of the ISO-Standard reverberation room, extended to lower frequencies than predicted from theoretical calculations based on flow resistivity values.

A new absorber was designed and tested, which has the dimensions of existing BBC type A modular absorbers (580 × 580 × 183.5 mm deep). The sound insulation of the absorber is shown in Fig. 17. The construction of the absorber is shown in Fig. 18. It consists of a box with 9.5 mm plywood sides and a 4 mm plywood back, filled with RW2 grade Rockwool (cut to 560 × 560 × 175 mm). The front of the box can either be covered with fabric and chicken wire, or with 20% perforated hardboard.

The advantages of the new design over the existing BBC wideband absorber (type A8/A9) are:

1. A smoother absorption coefficient curve, covering the same frequency range.
2. A less complicated construction, which should make it cheaper (materials costs for the existing A8/A9 absorber and the new design are comparable).
3. The new absorber (with no front panel) weighs 4.9 kg compared with 6.8 kg for the A9 absorber.

The new absorber successfully achieves the combined performance of A2 and A3 absorbers. As



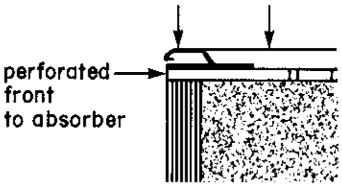


Fig. 18 - The construction of the wideband absorber.

with the existing wideband absorber (A8/A9), the number of modular absorbers required in a studio area would be approximately half the number required if A2 and A3 absorbers were used. Also, because the low and high frequency absorption is combined in one modular absorber, difficulties should not arise with the positioning of the absorbers in the room (A2 low frequency absorbers have to be positioned with care because they are quite reflective at higher frequencies).

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APPENDIX

Low Frequency Absorber Measurements

Fig. A1 shows the absorption coefficient of a modular absorber (of approximate dimensions 580 × 580 × 180 mm) containing RW2 grade Rockwool, with one 3 mm hardboard facing panel or one 4 mm plywood facing panel. In two experiments, the absorber was measured on battens with either facing panel upwards. The absorption coefficients for both mounting conditions are very similar. The results are compared with the absorption coefficient of an A10 absorber. As expected from earlier duct measurements[9], the absorption coefficient curve for the box containing Rockwool has a narrower peak of absorption, at a higher frequency than for the A10 (which contains 'Supawrap' loft insulation).

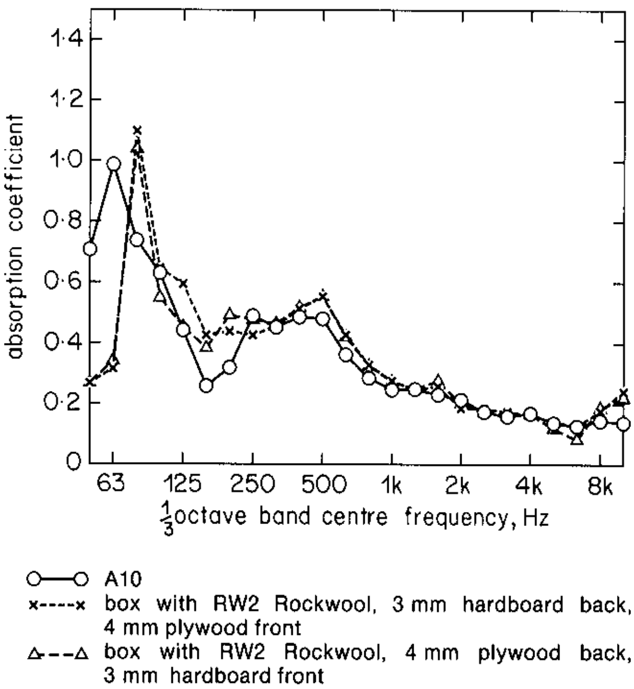

Fig. A1 - Various low frequency absorbers.