BBC RD 1995/7

BBC

RESOURCES

Research and Development Report

FURTHER INVESTIGATIONS OF PARTITIONS HAVING BUILT-IN ACOUSTIC TREATMENT

G.D. Plumb, M.A. (Cantab)

Research and Development Department
Technical Resources Division
THE BRITISH BROADCASTING CORPORATION

BBC RD 1995/7

FURTHER INVESTIGATIONS OF PARTITIONS HAVING BUILT-IN ACOUSTIC TREATMENT

G.D. Plumb, M.A. (Cantab).

Summary

Laboratory measurements were made of the sound insulations and absorption coefficients of a range of metal-framed partitions having built-in acoustic treatment. The partitions were made using glass wool and gypsum boards. The sound insulations of the single leaf partitions having built-in acoustic treatment were considerably lower than those of comparable partitions made using mineral wool, gypsum boards and fibreboard. For the double leaf partition having built-in acoustic treatment, the sound insulations were, on average, 8 dB higher than those of the comparable partitions containing mineral wool.

The use of the new double and triple leaf partitions containing built-in acoustic treatment should result in similar savings of floor areas to those obtained by using the partitions containing mineral wool as built-in acoustic treatment. However, it should be possible to obtain a flatter reverberation time curve using the new partitions and the sound insulations should be higher, provided that double leaf partitions are used.

Issued under the Authority of

Research & Development Department,
Technical Resources Division
BRITISH BROADCASTING CORPORATION

General Manager
Research & Development Department

(R013)

1995

FURTHER INVESTIGATIONS OF PARTITIONS HAVING BUILT-IN ACOUSTIC TREATMENT

G.D. Plumb, M.A. (Cantab).

FURTHER INVESTIGATIONS OF PARTITIONS HAVING BUILT-IN ACOUSTIC TREATMENT

G.D. Plumb, M.A. (Cantab).

1. INTRODUCTION

Partitions containing built-in acoustic treatment have already been designed and tested[1]. The primary purpose of building-in acoustic treatment is to reduce the overall thicknesses of the partitions and therefore increase the available floor areas in studios. The expected outcome of building-in acoustic treatment was a reduction in sound insulation. The partitions already tested were made using mineral wool, gypsum board and fibreboard.

For these partitions, there was too much overlap in the performances of the low and high frequency absorbent sections of the partitions. This overlap was a consequence of the materials used, and resulted in an excess of absorption at mid frequencies. At the time, this was not considered to be a difficulty. This was because the partitions were only intended for use in certain very low cost studio areas where the acoustic performances were of secondary importance to the space saving requirements.

As a result of more recent work[2,3], the combination of glass wool and gypsum boards alone in partitions having built-in acoustic treatment, was expected to result in better overall acoustic performances. The range of low cost studios in which partitions having built-in acoustic treatment could be used should then be increased by the use of the new partitions.

Measurements were made of the sound insulations and absorption coefficients of a number of partitions that used gypsum boards and glass wool[4] as built-in acoustic treatment. It was expected that the sound insulations of the new partitions would be comparable with those of the older designs of partitions; also that there would be less overlap in the absorption coefficient curves for the low and high frequency absorbent sections of the partitions.

2. THE DESIGN STRATEGY

Most of the absorption of the new partitions having built-in acoustic treatment was provided by glass wool in the cavities of the absorbent leaves. Moderate depths of this glass wool have been shown[2] to provide reasonable wideband absorption when the material was laid directly on a reflective surface. Two thicknesses of glass wool were used in the partitions tested; 75 mm and 150 mm.

For sections of the partitions having wideband absorption, the faces were covered with 24%* perforated, 0.7 mm thick, galvanised steel sheet. The perforated steel sheet is smooth, robust and should have virtually no effect on the absorption. Other materials, such as perforated hardboard or aluminium sheet, were rejected on grounds of insufficient strength or higher cost.

For relatively unabsorbent sections of the partitions, the faces were covered with unperforated 0.7 mm thick steel sheet. For these relatively unabsorbent sections, the cavity was still completely filled with glass wool for three reasons: to damp the motion of the steel, to provide adequate sound insulation and to prevent flanking transmission of sound at the boundaries between absorbent and relatively reflective sections. The relatively reflective sections were expected to provide a certain amount of low frequency absorption, because of damped resonances in the steel facing and in the plasterboard/coreboard backing to the absorbent leaves.

For single leaf partition tests, either one or two layers of 70 mm thick metal studs were used, the choice depending upon the depth of glass wool required. In practical studio constructions containing 150 mm depth of glass wool, it would be better to use 150 mm studs rather than two layers of 70 mm studs screwed together. In the tests, two layers of 70 mm studs screwed together were used to simplify the test procedure. For absorbent Shaftwall leaves (special types of leaves that can be constructed from one side only), 90 mm thick I studs (containing 70 mm thickness of glass wool) were used.

In multi-leaf partitions, only some of the leaves need to be absorbent. The remainder can be constructed as conventional Camdens. In a typical studio construction, the single leaf partitions may be either absorbent partitions or conventional metal-framed single Camdens[5]. For a double leaf partition, the Shaftwall leaf would typically face into the studio and would be absorbent. The other leaf would usually face into a corridor and could therefore be a conventional metal-framed single Camden. If both leaves of a double leaf partition were absorbent, the sound

* In the selections of steel sheet that were perforated the ratio of the area of the perforations to the area of steel remaining was 24:76.

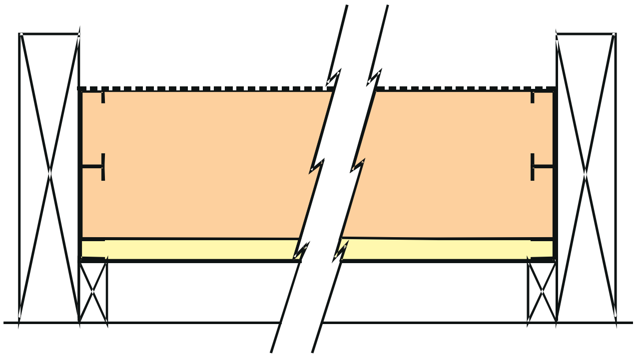


Fig. 1 - Cross-section through the frame containing an absorbent partition.

insulation would probably be inadequate. In a triple leaf partition, both outer leaves would usually face into studio areas and would be absorbent. The inner leaf would be non-absorbing, so could be a single Camden.

3. ABSORPTION COEFFICIENT MEASUREMENTS

ISO-Standard absorption coefficient measurements were made on a number of single leaf absorbent partitions, suspended horizontally above the floor of the receive room in the BBC Transmission Suite. They were built in to a frame of size 3.6 m wide by 3.0 m long, made from 25 mm thick chipboard. Fig. 1 shows a cross-section through the frame, containing one of the partitions tested. The frame was used for two reasons: to enclose the edges of the partitions with a reflective boundary and to support the partitions at a known distance above the floor. The width of the cavity between the partition and the floor was 50 mm. Fig. 2 shows the meanings of the symbols used in the keys to the subsequent graphs of measurements. Figs. 3 – 6 show ISO-Standard measurements of the absorption coefficients of the partitions built into the frame.

Fig. 3 shows the measured absorption coefficients of a perforated partition containing a 70 mm depth of glass wool. The infill pieces were 3000 × 600 × 19 mm thick coreboard, and the studs were 90 mm thick Shaftwall I studs. The absorption curve is typical of that usually obtained for a 70 mm thickness of a porous absorber[6]. The measurement is compared with that of a partition containing mineral wool. The two curves are very similar to each other, apart from some variation in the roll-off in the absorption at lower frequencies. The partition containing glass wool had a performance which extended lower in frequency than the partition containing mineral wool.

Fig. 4 shows the absorption coefficient of an unperforated partition containing a 70 mm depth of glass wool. The curve is typical of that observed for a damped membrane absorber. The peak of absorption, apparent at 100 – 125 Hz, is linked with a resonance in the metal front panel, which is damped by the glass wool. The peak of absorption for the partition containing glass wool is much higher than that for the partition containing mineral wool. This may be because glass wool provides a more suitable level of damping to the steel sheet than the mineral wool, or it may be a result of better sealing at the edges of the steel studs.

Fig. 5 *(see page 4)* shows the absorption coefficients of

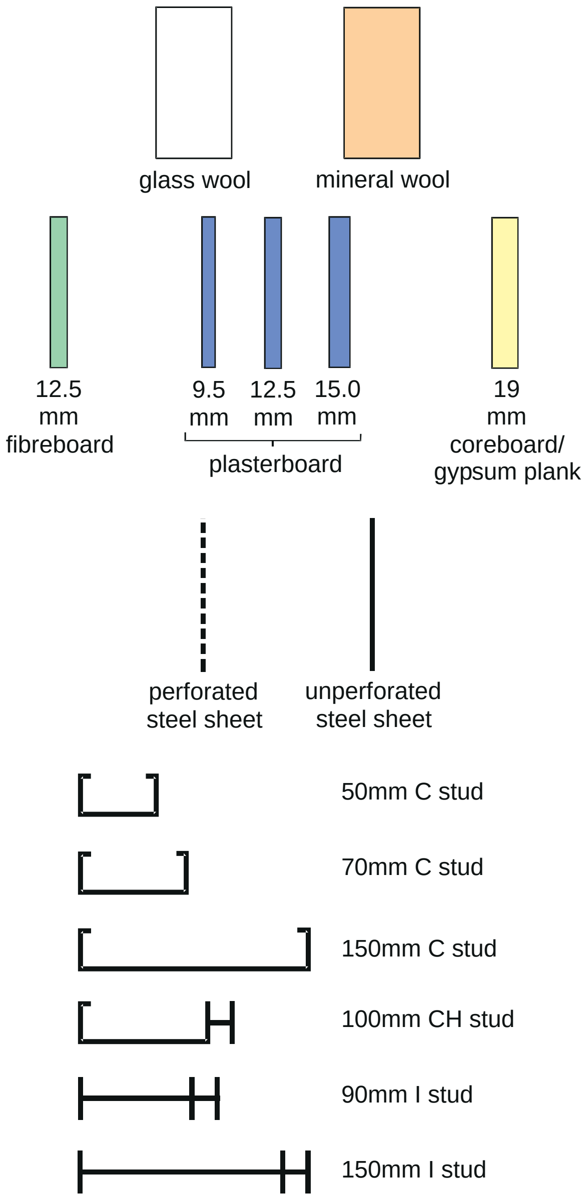


Fig. 2 - Symbols used in the keys to the graphs.

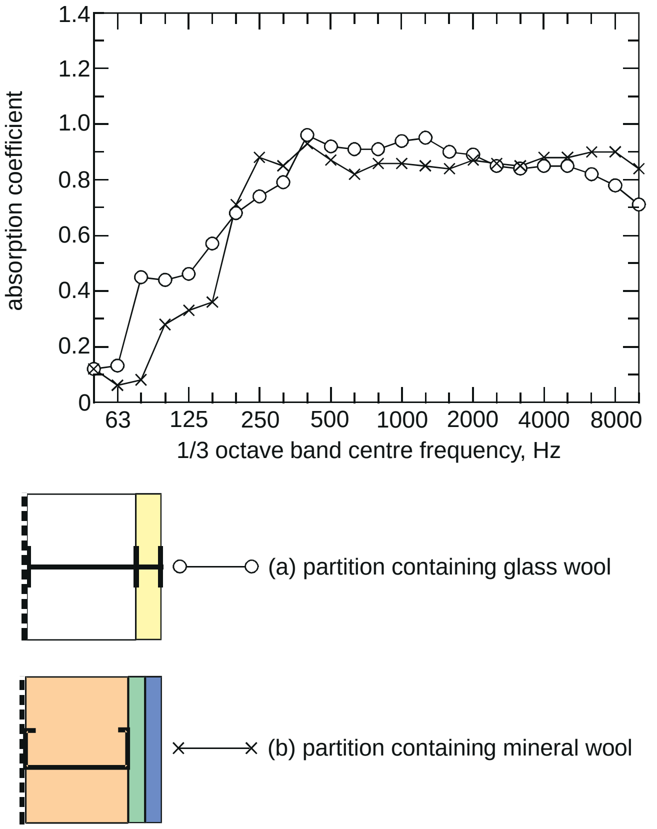


Fig. 3 - The absorption coefficients of perforated partitions containing 70 mm depth of insulation material.

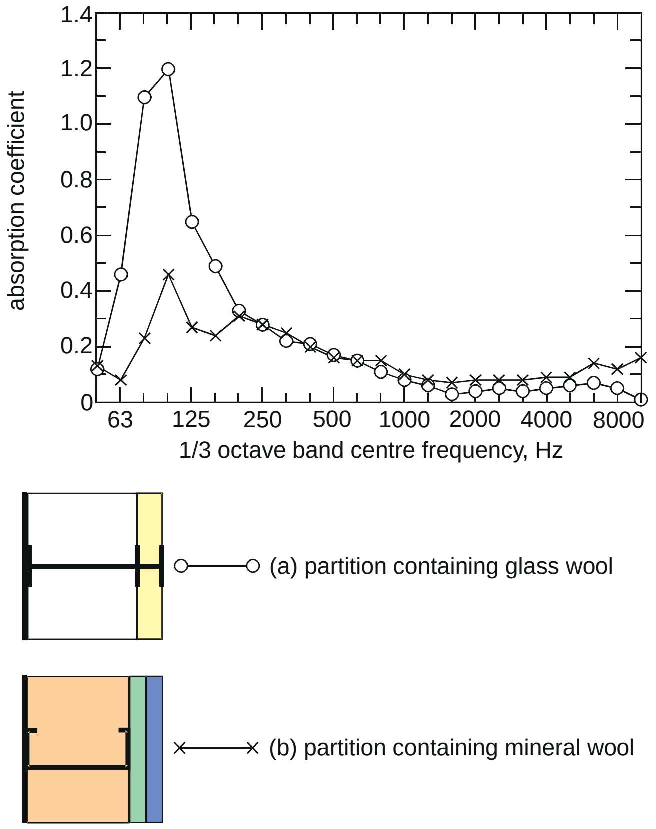


Fig. 4 -The absorption coefficients of unperforated partitions containing 70 mm depth of insulation material.

a perforated partition containing 150 mm depth of glass wool. The result is compared with that for a similar partition containing mineral wool. At higher frequencies, the two curves show quite close agreement with each other. The partition containing glass wool is a very effective wideband absorber, more so than the partition containing mineral wool. The reason for this difference in performance is not known. It is improbable that this large difference in performance is linked with the properties of the glass wool and mineral wool because they are both porous absorbers having similar densities. It may be that the coreboard, damped by the glass wool, is a more effective low frequency absorber than plasterboard and fibreboard damped by mineral wool.

Fig. 6 *(overleaf)* shows the measured absorption coefficients of an unperforated partition containing 150 mm depth of glass wool. The results are compared with those for a similar partition containing mineral wool. The peak of absorption at 100 Hz is linked with a resonance in the metal front panel, which is damped by the glass wool. The peak of absorption for the partition containing glass wool is much higher than that for the partition containing mineral wool. This may be because glass wool provides a more suitable level of damping to the steel sheet than the mineral wool, or it may be a result of better sealing at the edges of the steel studs. A comparison of the results with those for the unperforated absorber containing 70 mm thick glass wool (Fig. 4), shows that increasing the depth of glass wool lowers the frequencies over which the partition absorbs.

In a studio, a proportion of the walls will require perforated panels to control the reverberation times at mid and high frequencies. In addition, a proportion of the walls will be unperforated to provide low frequency absorption. The remainder of the walls can be conventional metal-framed Camdens which have relatively small levels of absorption.

Fig. 7 *(see page 5)* shows the overall absorption coefficients of partitions, having perforated sheets for 50% of the frontal area and unperforated sheets for the remainder, containing either 70 mm thick glass wool or 150 mm thick glass wool. The absorption coefficients were predicted from the absorption coefficients of the partition having perforated sheets for 100% of the frontal area, and unperforated sheets for 100% of the frontal area respectively. For this prediction, the mean absorption coefficient was calculated by summing the individual absorption areas, while assuming that the perforated and unperforated absorber regions did not interact. In previous work[1], this had been shown to be a reasonable approximation.

Results are compared with predictions for absorbent

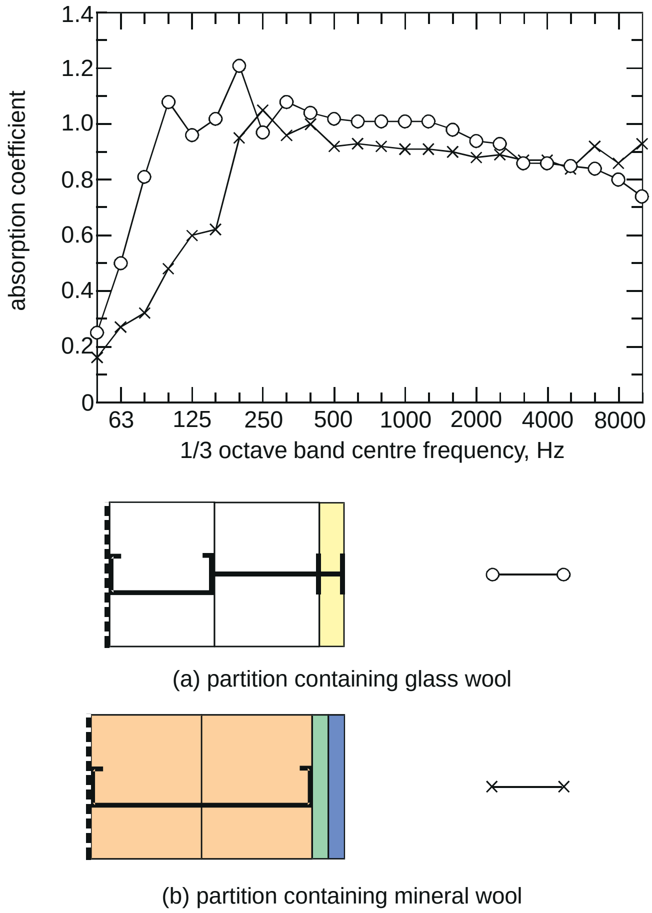


Fig. 5 -The absorption coefficients of perforated partitions containing 150 mm depth of insulation material.

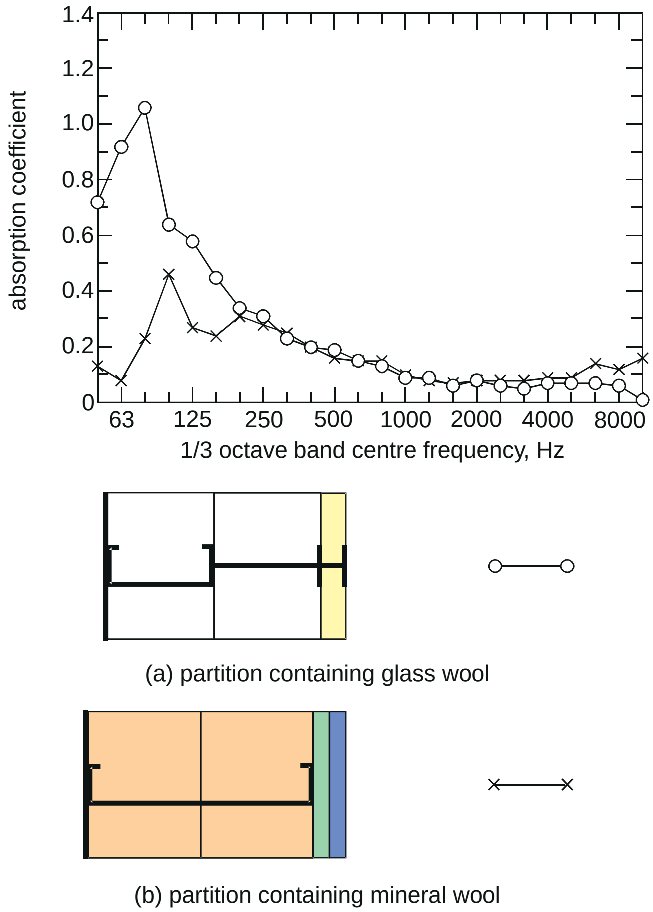


Fig. 6 -The absorption coefficients of unperforated partitions containing 150 mm depth of insulation material.

partitions containing mineral wool. For the partitions with mineral wool, perforated steel sheets were used for 33% of the frontal area, the remainder using unperforated sheets. The different percentages of unperforated faces for the glass wool and mineral wool partitions were chosen because the unperforated partitions with glass wool are much more effective as low frequency sound absorbers than the unperforated partitions with mineral wool.

At higher frequencies, the partitions containing glass wool have higher absorption coefficients than those containing mineral wool because a greater proportion of the faces of the partitions are perforated. At lower frequencies, the partitions containing glass wool have considerably higher absorption coefficients than those containing mineral wool because the unperforated glass wool partitions are more effective at absorbing low frequency sound than the partitions containing mineral wool. The partitions containing glass wool are much more suited to the acoustic treatment of rooms containing other high frequency absorbers such as carpet tiles or ceiling tiles. In comparison to the partition containing 150 mm glass wool, the measured absorption coefficient curve for the partition containing 70 mm depth of glass wool is more irregular at lower frequencies and has low levels of absorption below 80 Hz.

Fig. 8 shows the predicted reverberation times in a typical studio built from absorbent partitions containing either 70 mm or 150 mm depths of glass wool or mineral wool. For the calculations, the size of the studio was taken as 5 m × 4 m × 3 m high. The floor was covered with carpet tiles and the ceiling was treated with suspended ceiling tiles.

For the room design, the area of perforated partition was selected to give a mid band reverberation time of approximately 0.2 seconds. The area of unperforated partition was selected to give a reasonably flat absorption coefficient curve. For the partitions containing mineral wool, there was insufficient available wall area for the desired level of low frequency absorption. This accounts for the bass rises in the reverberation times for the studios constructed from partitions containing mineral wool. For the glass wool partitions, not all the partition area needed to be absorbent. Relatively untreated areas were provided by using conventional metal-framed Camdens.

Above 250 Hz, the reverberation time curves show

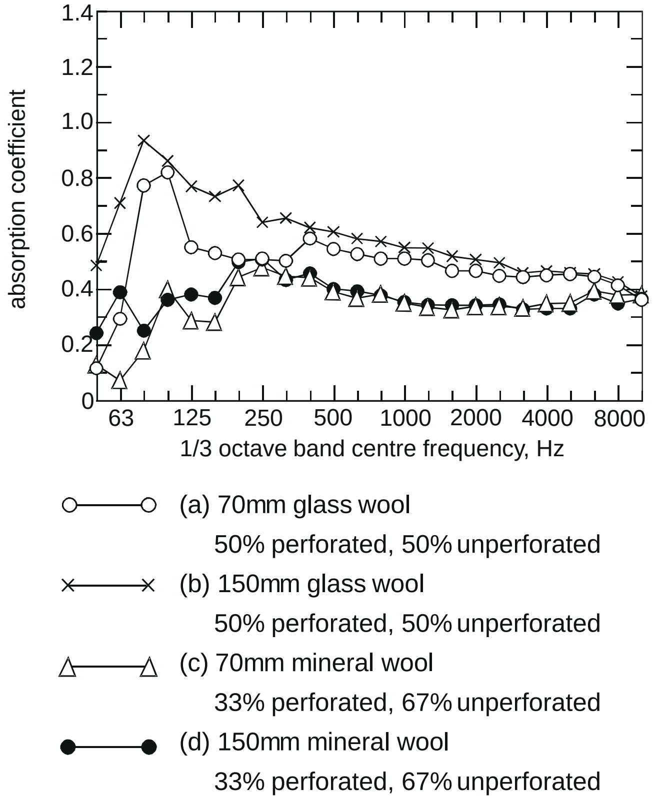


Fig. 7 - The predicted absorption coefficients of partitions having partially perforated and partially unperforated fronts.

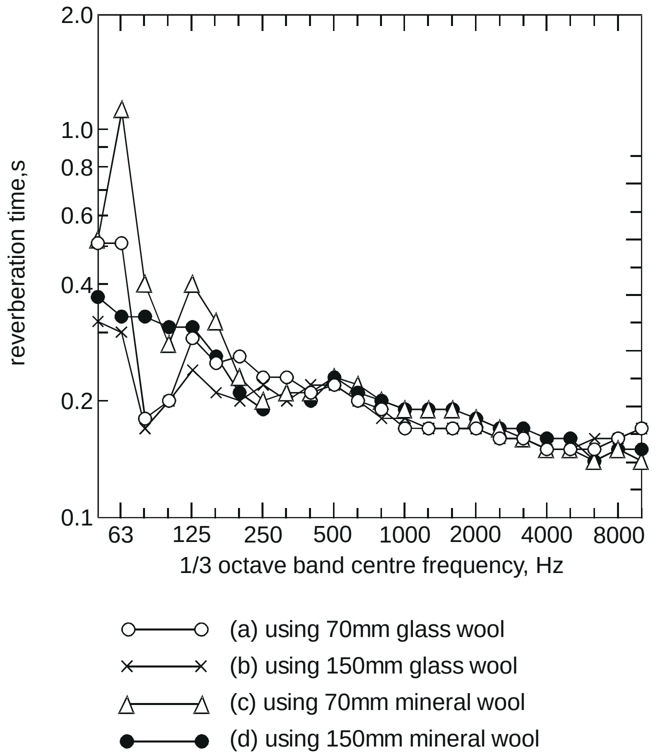


Fig. 8 - A prediction of the reverberation times in rooms constructed from partitions containing mineral or glass wool.

very close agreement with each other. Below 250 Hz, the reverberation time characteristics are somewhat irregular. With one exception, the rise in reverberation time at lower frequencies was excessive and additional low frequency absorption would be required. For 150 mm depth of glass wool, the rise in reverberation time at lower frequencies was well controlled and the predicted reverberation time curve was acceptably smooth. If absorption were the only criterion on which the partitions were selected, the partition containing a 150 mm depth of glass wool would be the preferred choice.

4. SOUND INSULATION MEASUREMENTS

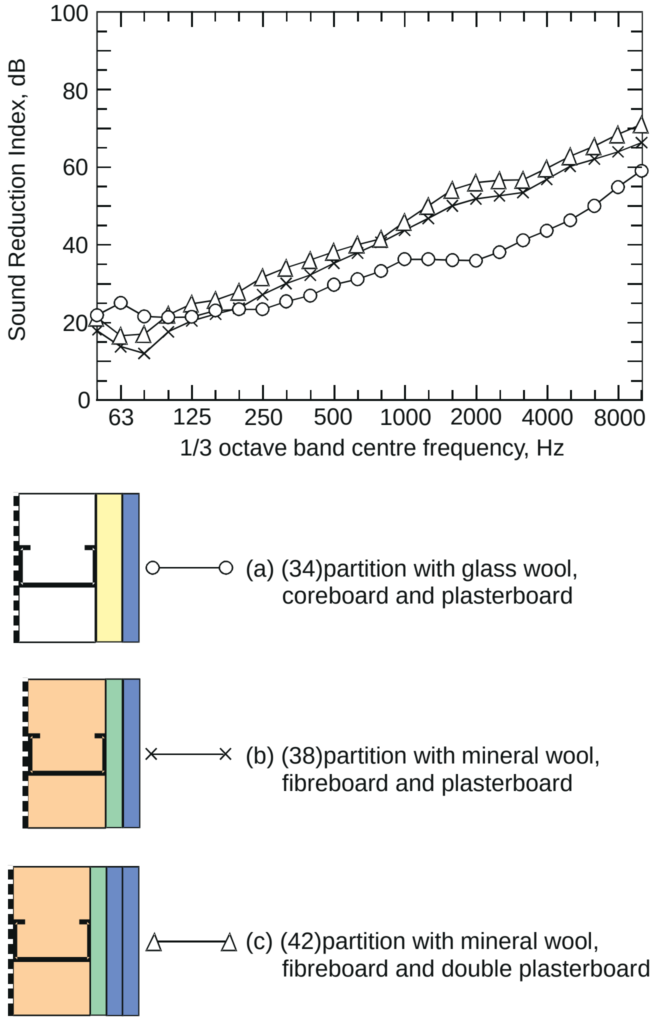
4.1. Single leaf partitions

The sound reduction indices were measured of a variety of single leaf partitions built into the aperture between the source and receive rooms in the BBC Transmission Suite. The results are shown in Figs. 9, 10, 11 and 12. Either 70 mm or 150 mm thick metal studs were used, completely filled with either one or two layers of compressed 75 mm thick glass wool batts, as appropriate. On one side of the studs, a single layer of 19 mm thick gypsum plank was fitted (with the boards installed horizontally), followed by one layer of 12.5 mm thick plasterboard. The joints were filled with acoustic sealant. Either unperforated or 24% perforated steel sheets (0.7 mm thick) were screwed to the other side of the studs.

Fig. 9 *(overleaf)* shows the sound insulations of a perforated partition containing a 70 mm thickness of glass wool. The sound insulations above 200 Hz were considerably lower than those of the partitions containing mineral wool. The reason for this is not known although considerable leakage of sound at the perimeter of the partition was observed when listening in the receive room.

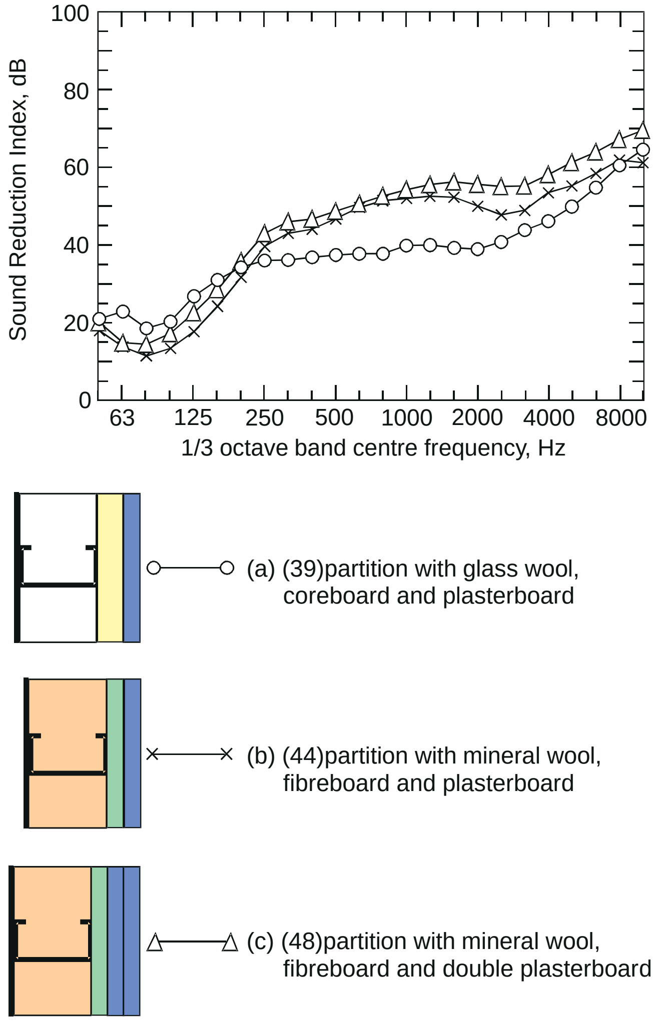
No specific reason for the weakness was discovered on dismantling the partition. It may be that it is more difficult to reliably seal the joint at the edges of the gypsum plank and plasterboard layers than the joint at the edges of the plasterboard and fibreboard layers. It is also possible that the glass wool is less effective than mineral wool at preventing the transmission of the sound that has leaked through any gap.

Below 100 Hz, the new partition had higher sound insulations than the older partitions. This is due in part to the additional masses of the boards. It is also linked with the different fundamental resonant frequencies of the partitions which are related to the masses and stiffnesses of the boards.



(Rw values are shown in brackets)

Fig. 9 - The sound insulations of perforated partitions containing 70 mm depth of insulation material.



(Rw values are shown in brackets)

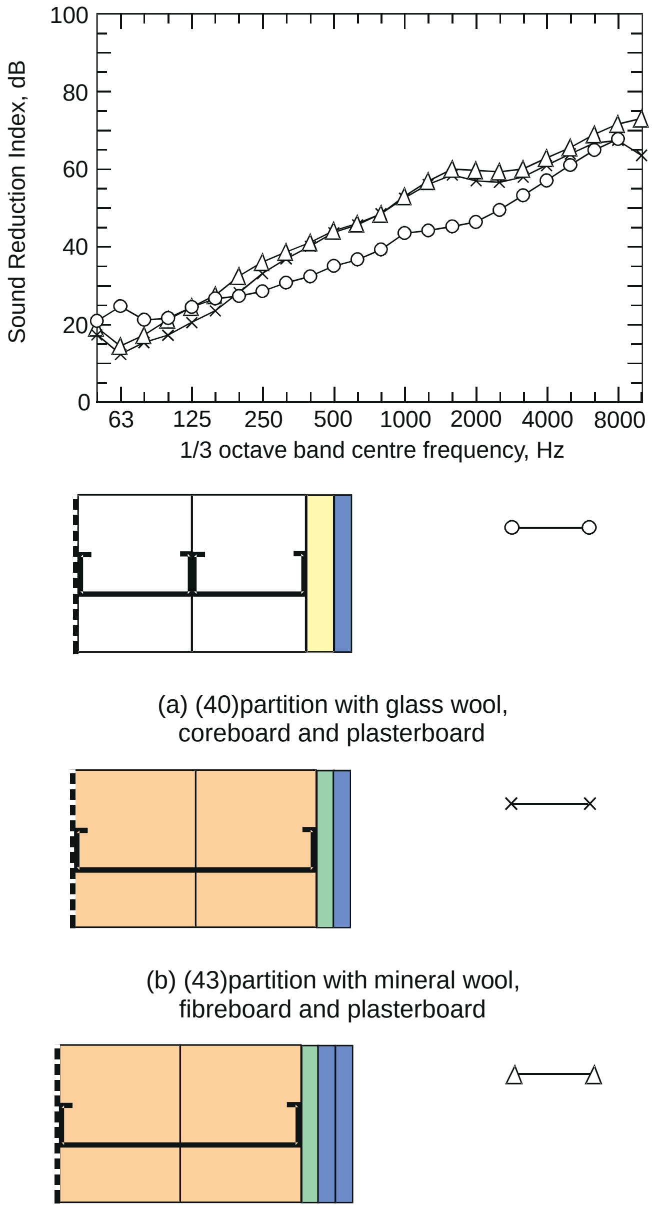
Fig. 10 - The sound insulations of unperforated partitions containing 70 mm depth of insulation material.

Fig. 10 shows the sound insulations of an unperforated partition containing 70 mm thickness of glass wool. As for the perforated partition containing 70 mm thickness of glass wool, the sound insulations above 200 Hz were considerably lower than those of the partitions containing mineral wool, so similar comments apply. The sound insulations below 200 Hz were higher than for the partitions containing mineral wool. As expected, the sound insulations, above 100 Hz, of the unperforated partition were considerably higher than those of the perforated partition. Below 125 Hz, the converse was true because of the different fundamental resonant frequencies.

Fig. 11 shows the sound insulations of a perforated partition containing a 150 mm thickness of glass wool. As before, the sound insulations above 200 Hz were considerably lower than those of the partitions containing mineral wool, and the sound insulations below 100 Hz were higher than for the partitions with mineral wool. Compared with the perforated partition containing 70 mm thickness of glass wool, the partition containing 150 mm thickness of glass wool has appreciably higher sound insulations above 100 Hz. This is because the greater thickness of glass wool absorbs more of the sound that has leaked past the plasterboard and gypsum plank layers. Below 125 Hz, the two partitions had similar sound insulations because the masses of the two partitions were similar.

Fig. 12 shows the sound insulations of an unperforated partition containing a 150 mm thickness of glass wool. In this case, the overall performance of the partition is comparable to that of the partitions containing mineral wool. The sound insulations between 315 Hz and 2 kHz were lower than those of the partitions containing mineral wool and the sound insulations below 160 Hz were higher than for the partitions with mineral wool.

Compared with the unperforated partition containing



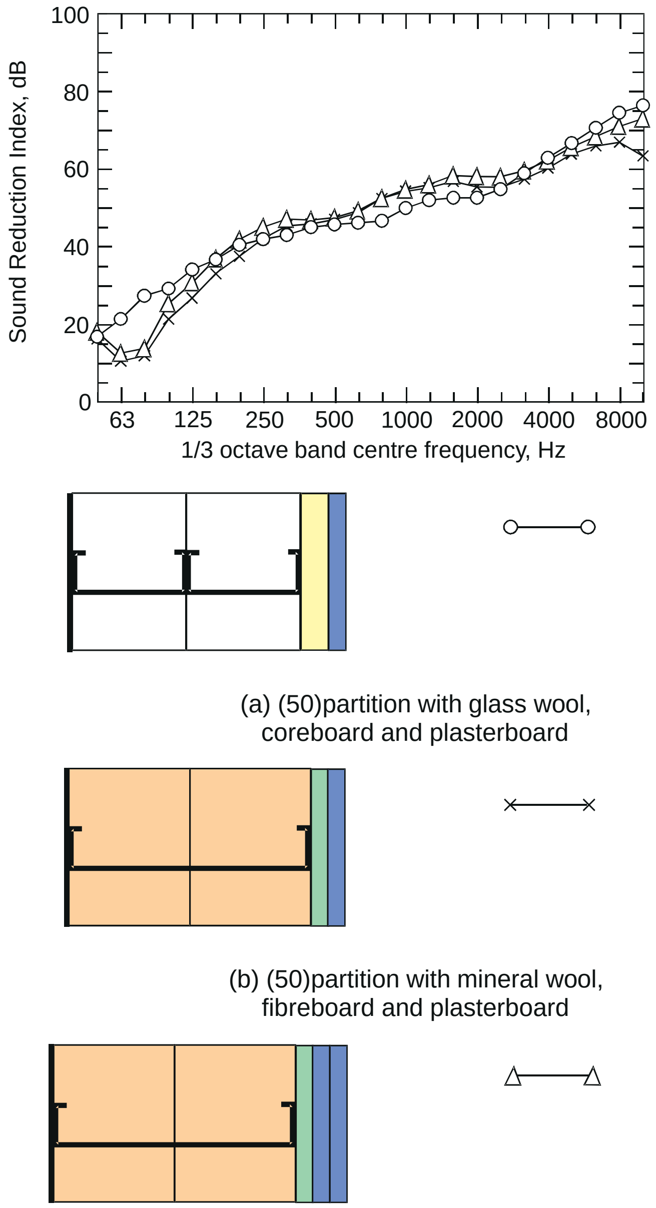
(a) (40)partition with glass wool, coreboard and plasterboard

(b) (43)partition with mineral wool, fibreboard and plasterboard

(c) (45)partition with mineral wool, fibreboard and double plasterboard

(Rw values are shown in brackets)

Fig. 11 - The sound insulation of perforated partitions containing 150 mm depth of insulation material.



(a) (50)partition with glass wool, coreboard and plasterboard

(b) (50)partition with mineral wool, fibreboard and plasterboard

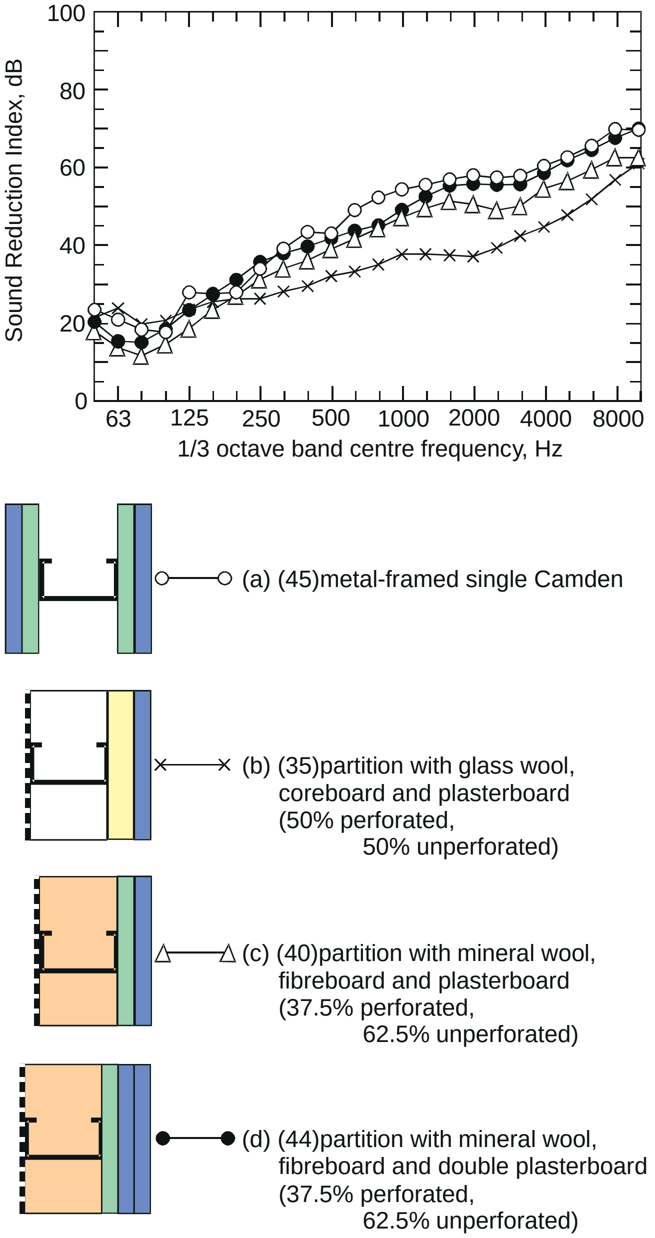
(c) (52)partition with mineral wool, fibreboard and double plasterboard

(Rw values are shown in brackets)

Fig. 12 - The sound insulations of unperforated partitions containing 150tmm depth of insulation material.

70 mm thickness of glass wool, the partition containing 150 mm thickness of glass wool had appreciably higher sound insulations above 63 Hz; the reason for this being that the greater thickness of glass wool absorbs more of the sound that has leaked past the plasterboard, gypsum plank and steel layers. Below 80 Hz, the thicker partition had lower sound insulations than the thinner partition because of the different fundamental resonant frequencies of the two partitions. For the unperforated partition containing 150 mm thickness of glass wool, the sound insulations, above 63 Hz, were considerably higher than those of the perforated partition containing 150 mm glass wool, because the partition was less porous. Below 80 Hz, the converse was true because of the different fundamental resonances.

In selecting a suitable partition construction, it must be remembered that a proportion of the face of the partition will be covered with perforated steel and the remainder with unperforated steel. The relative proportions of each covering will depend on the levels of low and mid/high frequency absorption required. The proportion of each facing present will also affect

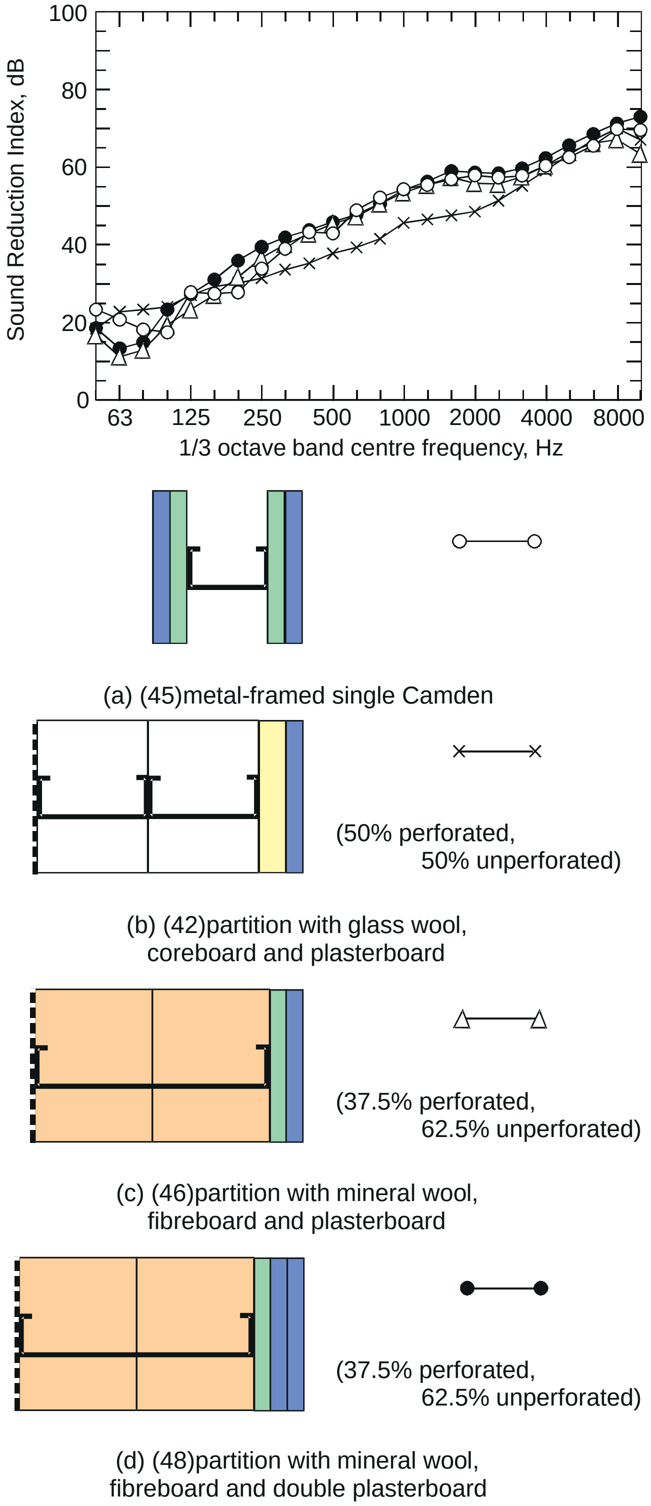


(Rw values are shown in brackets)

Fig. 13 - Predictions of the sound insulations of single leaf partitions containing 70 mm depth of insulation material and having combined perforated and unperforated steel fronts.

the overall sound insulation. For ease of studio construction, it would be worthwhile to select the same stud width and to have the same number of layers of plasterboard, whatever the facing.

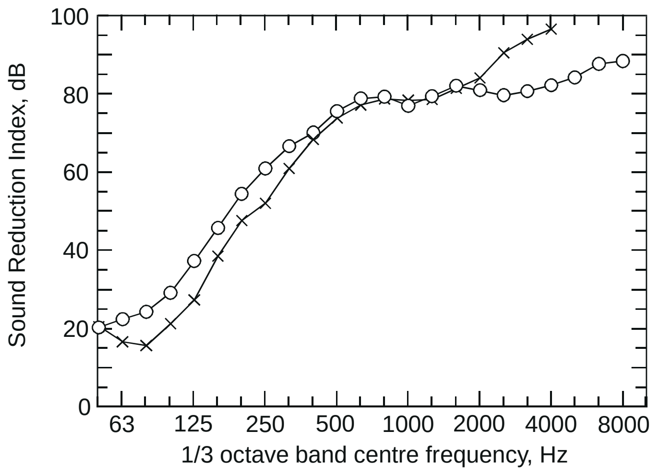
For a typical studio made from the new partitions having built-in acoustic treatment, between 50% and 70% of the wall area would have to be covered with perforated steel and the remainder would be unperforated. Figs. 13 – 14 show predictions of the sound insulations of single leaf partitions having perforated steel sheets for 50% of the frontal area and

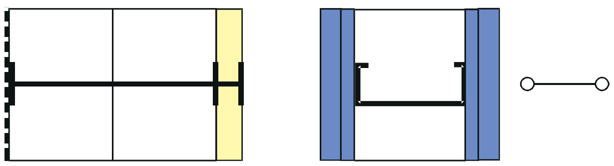


(Rw values are shown in brackets)

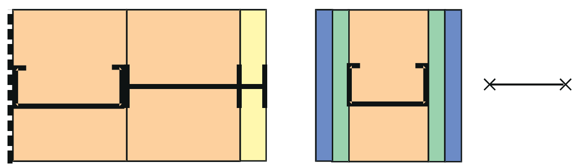
Fig. 14 - Predictions of the sound insulations of single leaf partitions containing 150 mm depth of insulation material and having combined perforated and unperforated steel fronts.

unperforated sheets for the remainder. The predictions were derived by assuming that the perforated and unperforated sections of the partitions were essentially two independent partitions with areas given by the





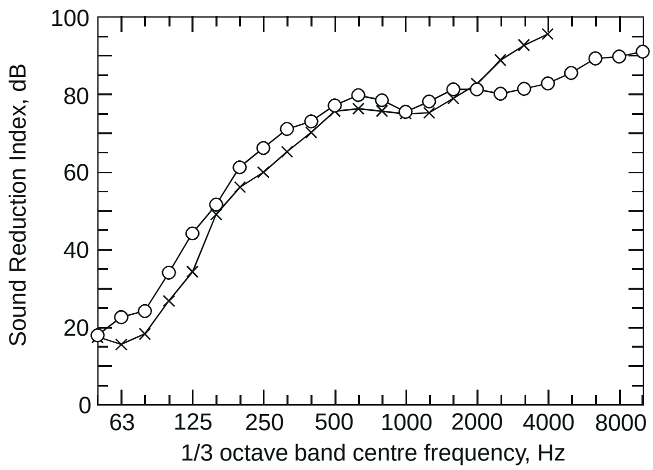
(a) (64)partition with glass wool, coreboard and plasterboard

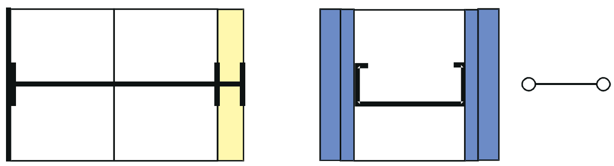


(b) (55)partition with mineral wool, coreboard, fibreboard and plasterboard

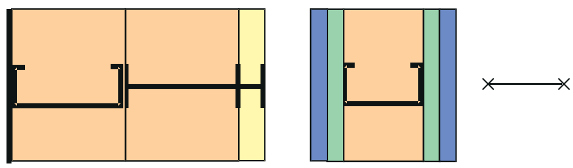
(Rw values are shown in brackets)

Fig. 15 - The sound insulations of double leaf perforated partitions.





(a) (70)partition with glass wool, coreboard and plasterboard



(b) (63)partition with mineral wool, coreboard, fibreboard and plasterboard

(Rw values are shown in brackets)

Fig. 16 - The sound insulations of double leaf unperforated partitions.

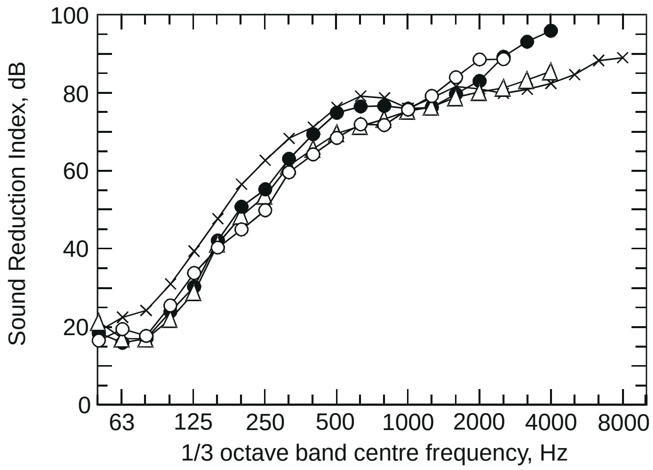
areas of the front panels. In previous work, this has been shown to be a reasonable approximation, although the perforated and unperforated sections of the partitions will not be fully independent. The sound insulation predictions were calculated by summing the sound powers flowing through the perforated and unperforated sections. The predictions were calculated from the sound reduction indices of the partition having perforated steel sheets for 100% of the frontal area, and for the sound reduction indices at the partition having unperforated steel sheets for 100% of the frontal area.

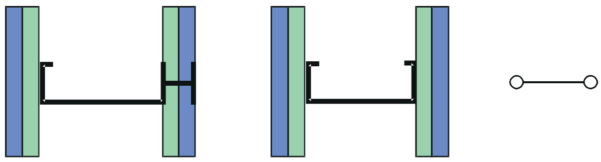
The overall sound insulations of the new single leaf partitions with mixed facings are considerably lower than those of comparable partitions containing mineral wool (having perforated steel sheets for 37.5% of the frontal area and unperforated sheets for the remainder). The performances of the newer partitions are also much lower than the performance of the single leaf metal-framed Camden. Because of the difficulty of constructing a reliable single leaf partition of the newer type, it would be sensible to use a conventional single leaf Camden partition for those small areas of studio walls where single leaf partitions are sometimes required.

4.2. Double leaf partitions

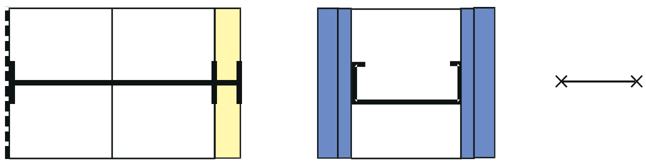
Shaftwall studs (150 mm thick) were used in the absorbent leaves of the double leaf partitions. The backs of the Shaftwall leaves were made from 19 mm thick coreboard. The Shaftwall leaf was filled with two layers of compressed 75 mm thick glass wool batts. Either unperforated or perforated steel sheets (0.7 mm thick) were screwed to the fronts of the studs. The first leaves of the double leaf partitions to be constructed were made from 15 mm plasterboard and 9.5 mm plasterboard fitted to 70 mm studs filled with 75 mm thick glass wool batts.

Figs. 15 and 16 show the results of sound insulation measurements on the double leaf partitions with perforated and unperforated fronts. Between 63 Hz and 800 Hz, the performances of the partitions containing glass wool were considerably higher than those of the partitions containing mineral wool. This is because the partitions containing glass wool have more mass and better internal damping. Above 1.6 kHz, the partitions containing glass wool had lower sound insulations than the partitions containing mineral wool, presumably because the sealing at the perimeter of the partition was not so effective. The sound insulations of the unperforated partitions were higher than those of the perforated partitions from 100 Hz to 630 Hz.

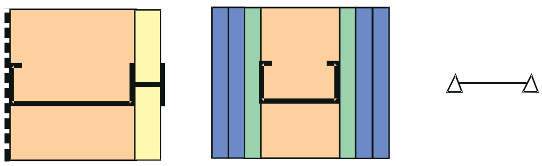




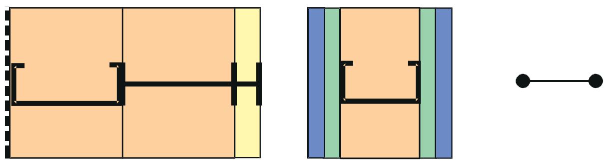
(a) (58)metal-framed double Camden



(b) (66)partition with 150mm glass wool, coreboard and plasterboard



(c) (57)partition with 75mm mineral wool, coreboard, fibreboard and double plasterboard



(d) (58)partition with 150mm mineral wool, coreboard, fibreboard and plasterboard

(Rw values are shown in brackets)

Fig. 17 - Predictions of the sound insulations of double leaf partitions containing different depths of insulation material and having combined perforated and unperforated steel fronts.

Otherwise, the sound insulations were comparable with each other.

Fig. 17 shows predictions of the sound insulations of a double leaf partition containing glass wool and having perforated sheets over 50% of the frontal area, the remainder being unperforated. The performance of the partition containing glass wool, between 63 Hz and 800 Hz, was appreciably higher than those of the partitions containing mineral wool (having perforated sheets over 37.5% of the frontal area, the remainder being unperforated) and of the metal-framed double Camden itself. The absorbent double leaf partition is ideally suited to studio construction.

5. CONCLUSIONS

The primary source of absorption in the absorbent, metal-framed partitions was glass wool completely filling the cavities of the partitions. The absorbent leaves were faced with either 0.7 mm thick perforated or 0.7 mm thick unperforated steel sheet, the relative proportions of each facing determining the overall sound insulation and absorption. For aesthetic reasons, it may be considered necessary to cover the partitions with a proprietary stretched fabric system. The fire performances of partitions having glass wool as built-in acoustic treatment should be comparable with, or better than, those of partitions having mineral wool as built-in acoustic treatment.

The two most significant factors that determine the absorptions of these partitions are the type of facing and the thickness of the glass wool (and consequently the overall thickness of the absorbent leaves). The partitions absorb at low frequencies when the facing is unperforated and at mid and high frequencies when the facing is perforated. Ideally, the absorbent leaves should contain a 150 mm depth of glass wool. With 150 mm depth of glass wool, a typical overall reverberation time curve for a studio design was acceptably flat from 50 Hz to 10 kHz. For even more flexibility in the acoustic design, it would be possible to combine the use of the absorbent partitions containing glass wool and mineral wool.

In a room, the relative positioning of the wideband and low frequency absorbent sections will be important. The low frequency absorbent sections are very reflective at higher frequencies and should not be placed at the listener's ear height. Otherwise flutter echoes or early reflections might occur. The low frequency absorbent sections could be placed behind the loudspeakers and behind bays of equipment. The wideband and low frequency absorbent sections should be well interspersed to give adequate diffusion of the sound field. However, when particularly high levels of sound insulation are required between two rooms, relatively small areas of the wideband absorbent partitioning should be used on the partition between them.

The sound insulations of single leaf partitions having glass wool as built-in acoustic treatment were considerably lower than those of comparable mineral wool partitions. Therefore, these new designs of single leaf partitions should not be used for studio construction. The sound insulations of the double leaf partition having glass wool as built-in acoustic treatment were, on average, 8 dB higher than those of comparable partitions containing mineral wool. It is predicted that the performance of a triple leaf partition having glass wool as built-in acoustic treatment should also be acceptable.

The use of double and triple leaf partitions containing glass wool as built-in acoustic treatment should give similar savings in studio floor areas to those obtained by using the partitions having mineral wool as built-in acoustic treatment. However, it should be possible to obtain a flatter reverberation time curve using the new glass wool partitions and the sound insulations should be higher.

6. REFERENCES

1. PLUMB, G.D. 1993. Metal-framed partitions with reduced thicknesses: part 2 – built-in acoustic treatment. BBC Research Department Report No. BBC RD 1993/6.

2. BAIRD, M.D.M. 1994. A wideband sound absorber for television studios. BBC Research Department Report No. 1994/12.

3. PLUMB, G.D. 1994. Further measurements of the sound insulations of metal-framed partitions. BBC Research Department Report BBC RD No. 1994/7.

4. ANON. 1991. The white book. British Gypsum Limited.

5. PLUMB, G.D. 1991. The airborne sound insulations of metal-framed partitions. BBC Research Department Report BBC RD No. 1991/10.

6. PLUMB, G.D. 1992. A modular wideband sound absorber. BBC Research Department Report BBC RD No. 1992/11.

Published by BBC RESEARCH & DEVELOPMENT DEPARTMENT, Kingswood Warren, Tadworth, Surrey, KT20 6NP