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SOUND INSULATION WITHIN BUILDINGS

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INTRODUCTION

One of the many functional requirements of buildings is that they should be designed to protect users from noise. The architect must consider a number of factors if he or she wishes to ensure that this will be achieved in practice:

1. Planning of the building to separate noisy areas from noise-sensitive areas
2. Specification of appropriate continuous background noise levels
3. Selection of appropriate sound-insulating elements
4. Good detailing and specification to ensure a good standard of workmanship on site

Factors 3 and 4 are considered in this paper. A number of case studies are presented in which transmission losses ranging between 5 dB and 95 dB were achieved in practice, though in some cases the result was not achieved by design.

OPEN PLAN OFFICES (TRANSMISSION LOSS 5 TO 15 dB)

Workers in open plan offices must be protected from the noise of office machines and speech in neighbouring work stations. In the open air, small sound sources radiate sound in all directions equally. The inverse square law dictates that the sound level diminishes at a rate of 6 dB per doubling of distance. In open plan offices, in addition to the direct sound, some sound is reflected from the walls ceiling and other surfaces in the room. The more absorbent the room surfaces, the lower the reflected sound level and the closer the situation becomes to the open air where the 6 dB rule applies. The finishing materials which would provide a result close to this ideal are often not acceptable to the architect and, as a result, the potential benefit of office screening systems is often not realised.

Bickerdike Allen Partners were engaged to investigate a problem of noisy conditions in an existing open plan office. See figure 1. It was reported that there was inadequate privacy between work stations and that voices could easily be overheard. The area was divided into 17 work stations by means of an integral screening and table system. The screens were 1.1 m high except around one corner work station where they were 1.6 m high. There was a carpet on the floor, the walls were of plaster or plasterboard finish with windows along the external wall. Mineral fibre tiles were installed on the ceiling.

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The rate of attenuation of sound in the office was measured by generating noise at a work station and measuring the sound pressure level at this and other work stations. The transmission loss is represented by subtracting the level measured at each work station from the level at 1 m. The results were obtained over the speech interference frequency range of 400 to 2500 Hz. The transmission loss was measured at five work stations along the length of the office where there was a clear line of sight between the source and receiver above the small screens. The source was then moved into the work station behind the 1.6 m screens and the transmission loss measurement repeated. The results are summarised in the table 1.

TABLE 1

Distance m	Attenuation, dB (400 - 2500) Clear sightline	Source 1m behind 1.6m screen	Effect of screen
3	5.0	8.9	4.9
5	9.6	12.3	2.7
8	13.3	15.6	2.3
10	15.6	16.4	0.8
13	16.0	17.8	1.8

The transmission loss between any pair of unscreened work stations in this office was between 5 and 16 dB. For the work station with the tall screens, the transmission loss was between 9 and 18 dB

Potential improvement - no screening

In table 2, the measured transmission loss is compared with that expected on the basis of the inverse square law. This suggests that a theoretical improvement in attenuation of 4 - 5 dB could be achieved by eliminating all reflected sound - that is, by applying efficient sound absorbers to all reflective surfaces. In practice the improvement would be less than this. In a series of tests conducted by Parkin and West [1] in an open plan office with similar features, improvements of between 1 and 4 dB only were achieved by this method. (See table 2).

TABLE 2

	ATTENUATION (dB) AT DISTANCE (m) 2	3	5	10	m
Measured		5	10	16	dB
Inverse square law		10	14	20	dB
Max improvement (theoretical)		5	4	4	dB
Parkin & West results [1]					
Untreated office	4		10	14	dB
Walls and ceiling treated	5		12	18	dB
Improvement achieved	1		2	4	dB

It can therefore be concluded that the application of absorbers to the boundaries of an open plan office will not achieve a significant increase in transmission loss as long as there is a clear line of sight between office users. To achieve significant improvements, it is necessary to adopt taller screens which interrupt the line of sight between work stations.

Potential improvement - screening

When screens are introduced to interrupt the line of sight between work stations, sound can be transmitted only by diffraction over the screen and by reflection from the room surfaces (assuming that transmission through the screen is negligible). Simple barrier attenuation calculations, relating to diffraction over the barrier only and ignoring reflection effects, indicate that for a single 1.6 m screen, the transmission loss between neighbouring work stations should be 21 dB and between the most distant work stations should be 33 dB. The measured results of 9 and 18 dB, respectively, are determined mainly by reflection from the room surfaces. The reflected sound energy must be reduced before a significant benefit can be obtained from tall screens.

To achieve a significant reduction in reflected sound energy it is necessary to install an efficient absorber. In general, every halving of the reflected sound energy results in an increase in transmission loss of 3 dB. On this basis, it would be necessary to provide an absorption coefficient of 0.9 to achieve a 10 dB transmission loss. In the office in question, the mineral fibre ceiling tile had absorption coefficients in the range 0.2 - 0.4, corresponding to a transmission loss of only 1 - 2 dB in the reflection path. The walls of the room were substantially reflective.

It was considered possible to improve the overall transmission loss between work stations by approximately 10 dB by implementing the following remedial measures:

The introduction of tall screens, incorporating a solid core and absorbent faces.
The replacement of the existing ceiling tile with an efficient absorber (absorption coefficient close to 1)
The application of an efficient acoustic absorber on the upper walls, or the butting of screens against the walls to prevent reflections around them.

Such measures place major restrictions on the architect's freedom to develop an attractive interior design. Though a 10 dB improvement may be achieved, an overall transmission loss of 15 dB between neighbouring work stations would not normally provide privacy.

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DEMOUNTABLE CELLULAR OFFICES (TRANSMISSION LOSS 35 dB)

Whilst office users may accept that acoustic privacy is not achieved between neighbouring work stations in open plan offices, a lack of privacy between cellular offices is more difficult to accept. In practice, problems frequently arise and are usually caused by one or more of the following factors:

Inadequate brief: The client's requirements and expectations are not adequately defined and no appraisal is made of the reasonableness of these expectations or the ways in which they might conflict with other physical requirements.

Inadequate understanding of the physical principles: The acoustic properties of building materials are often not understood. As a result it proves difficult to appraise data provided by the manufacturers of "acoustic" materials and they are used incorrectly.

Inadequate attention to detail in design, specification and construction: Even when appropriate building materials have been selected, poor specification and/or workmanship during assembly can give rise to a poor result in practice.

Bickerdike Allen Partners were engaged to investigate a problem of poor inter-office sound insulation in a new office building. The airborne sound insulation was measured in accordance with BS 2750: Part 4: 1980, between two typical cellular offices. The results are shown on figure 2. The mean level difference (100 - 3150 Hz) is 26 dB. The client had been given to understand that the sound insulation between completed offices would be 43 or 45 dB, but it was not clear whether this was a mean value or a D_W value (according to BS 5821).

British Standard 8233: 1987, "Sound insulation and noise reduction for buildings" offers the following recommendations for sound insulation between cellular offices:

> In cellular office layouts the minimum desirable average sound insulation D between two offices is about 35 dB (D_W = 38 dB). Where privacy is required the minimum average sound insulation should be 45 dB (D_W = 48 dB) and even then it is possible that voices can be heard, but the conversation will not usually be understood.

It appears that the sound insulation expected by the client was equal to or approaching that required for privacy between offices.

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BS 8233 goes on to state:

> If demountable partitions are used in cellular offices it is likely that a standard of sound insulation between offices lower than that desirable for good privacy will have to be accepted. Components are usually thin and lightweight in construction, and if it is difficult to obtain an airtight fitting between them or at the basic structure of the building the sound insulation could be between 5 dB to 10 dB lower than expected.

In this case, it appears that the client was led to believe that he could have a better standard of sound insulation than is practicable.

The manufacturer's laboratory test results were available for the system and these corresponded to a mean level difference of 28 dB. See figure 2. Therefore the partition was not designed to achieve even the minimum criterion of 35 dB recommended for cellular offices. Recommendations were made to improve the system to a standard of at least 38 dB, making a small allowance for the difference expected between laboratory and field performance. This involved the application of a plasterboard / fibreglass laminate to one side of the demountable partition.

Investigations were undertaken to establish whether flanking transmission would jeopardise the overall result. The client advised that the sound insulation between another pair of offices on the same floor was much better. A 40 dB partition had been used and a result of 37 dB obtained on site. The poorer partition was found to have several potential sound flanking paths which were not present around the better partition. These are listed below together with the recommendation made to remedy the problem.

> Gap between the partition base and carpet.
> Proposed remedy: bed the partition tightly against the carpet, as was achieved by the better partition.
>
> Gaps between the partition head and ceiling. (The ceiling tiles above the better partition were cut).
> Proposed remedy: bed the ceiling tiles in mastic against the head of the partition.
>
> Void between the upper face of the ceiling tiles and the underside of the structural deck. (This already had a double skin plasterboard barrier on the line of the partition, but there were large gaps around and through it. The better partition was installed against a solid downstand beam).
> Proposed remedy: apply solid blocking and mastic to all gaps to ensure an airtight seal.

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The treatments recommended to improve the performance of the partition and to reduce flanking transmission can be reasonably expected to achieve the minimum standard of 35 dB between offices. However, when remedial measures of this kind are implemented, it becomes more difficult to dismantle the offices and relocate the partitions elsewhere and the principle behind the use of demountable partitioning is compromised.

DWELLINGS (TRANSMISSION LOSS 50 dB)

The Building Regulations 1985 provide detailed guidance on separating wall and floor constructions which provide reasonable sound insulation of about 50 dB (D) or more. This guidance has been developed from outline specifications given in earlier editions of the Building Regulations. Problems with new separating walls are most likely to arise when this guidance is ignored.

Bickerdike Allen Partners were engaged to investigate a problem of poor sound insulation in a block of flats and to make recommendations to remedy the problem. The complaint related to airborne sound insulation between master bedrooms on all levels. The separating wall was constructed of 100 mm autoclaved aerated concrete blocks laid on their sides to form a 225 mm blockwork wall. This was dry-lined on both sides with 13 mm plasterboard on plaster dabs creating a small cavity of approximately 12 mm on both sides. See figure 3. The overall mass of the construction was approximately 200 kg/m^2, significantly lower than the mass of 415 kg/m^2 recommended in the pre-1985 Building Regulations. One end of the separating wall was terminated by the inner concrete blockwork leaf of the external wall which was also dry-lined. The other end of the separating wall was terminated at a structural concrete wall to the foyer. The separating floor was a concrete waffle slab with a plasterboard ceiling below.

The level difference between bedrooms was measured and found to provide an average of 40 dB (43 dB, $D_{nT,w}$), approximately 10 dB below the required result. The main causes of the problem were inadequate overall mass and the presence of a gap between the head of the party wall and the waffle slab above. Vibration measurements were made to assess the transmission via flanking elements. It was concluded that any remedial treatment should deal with both the party wall and the external flanking wall. Flanking transmission via the floor/ceiling construction and inner flanking wall was considered to be insignificant.

In view of the disruption it would cause, it was decided not to rebuild the wall in dense masonry complying with the constructional specifications given in the Building Regulations. The block manufacturer provided information suggesting that the wall could meet the numerical requirements if the dry linings were removed, the gaps sealed and the wall rendered and plastered on both sides. A pilot study was carried out but the improvement obtained was modest and confined to the low frequency region.

The remedial specification finally adopted is shown on figure 3. This required the removal of the dry-lining on one side of the wall only, sealing of the gap at the top of the wall and the construction of an independent laminated wall lining of mass 40 kg/m^2. This reduced the width of the bedroom by 38 mm. The resulting level difference, D was 56 dB (60 dB, $D_{nT,w}$), exceeding minimum Building Regulations standards by approximately 6 dB.

In this example, the contractor had ignored the requirements of the Building Regulations and had relied instead on manufacturers' sound insulation data. The resulting shortfall in sound insulation was made worse by deviating from the manufacturers' constructional specifications and poor implementation of the work on site.

MUSIC PRACTICE ROOMS (TRANSMISSION LOSS 70 - 95 dB)

To achieve a degree of sound insulation which is significantly higher than that required between dwellings, it is necessary to incorporate structural isolation in the design. It is of paramount importance to obtain a high standard of workmanship on site if the sound insulation potential of isolated constructions is to be realised in practice.

Over a period of approximately 10 years, Bickerdike Allen Partners have been involved in the installation of approximately 20 music practice rooms in an existing music college. The constructional details of a pair practice rooms housing percussion instruments and an electronic music studio are shown on figure 4. Each room is constructed as a masonry box which sits within the existing building on isolating pads. These pads represent the only mechanical link between the practice rooms and the existing building. To ensure a high degree of isolation over the frequency range of musical instruments, the isolating pads have been selected to obtain a mass-spring resonance not exceeding 12 Hz. The walls are constructed of 225 mm brickwork rendered and plastered on the room side. The cavity between the rooms is 300 mm wide and contains a mineral fibre absorber. The resulting sound insulation (D) between rooms immediately after installation was approximately 70 dB.

After the construction of a rehearsal studio on site of a former locker room on the floor above these rooms, complaints were received from the user that the sound of percussion instruments could be heard from the room below. Sound insulation measurements were made and compared with the sound insulation measured immediately after completion. These are summarised in table 3.

TABLE 3

SOURCE ROOM	RECEIVING ROOM	MEAN LEVEL DIFFERENCE, dB 1980	1985	1985 after remedial works
Percussion	Rehearsal studio	-	57	70
Electronic	RS/lockers	69	62	73
Electronic	Percussion	71	62	69

The measurements indicated that the sound insulation between the basement practice rooms and the first floor area had diminished by 7 - 12 dB since the rooms were first completed. The sound insulation between the neighbouring practice rooms had decreased by 9 dB. Bridging of the structural isolation was suspected as the cause of failure and a detailed inspection revealed that there was solid bridging between the top of the practice room walls and the floor slab above. The original specification for this junction called for an airtight, flexible seal. The architect's detail showed a non-hardening mastic sealant gunned against a foam backing material. Though, in places, this detail had been implemented correctly, at most of the positions inspected, putty had been substituted in place of the non-hardening mastic. Over a period of time, the putty had hardened creating a solid junction between the isolated wall and the floor slab above.

The removal of this putty proved troublesome and could not be complete as some areas were now inaccessible without demolition of the rooms. When all the accessible putty had been removed, the sound insulation was remeasured. The results are summarised in table 3 where it can be seen that the former high performance was restored.

In a subsequent phase of development, a new pair of practice rooms were commissioned by the college to house percussion instruments and brass instruments. See figure 5 (a). In view of the power of the musical instruments concerned, it was considered necessary to improve on the sound insulation previously achieved, if possible. The area designated from these rooms was on the same basement slab as the rooms discussed above. Similar constructional details were adopted but, to avoid contact with existing columns, the cavity between the rooms was 350 mm wide rather than 300 mm.

The measured level difference in the completed building is shown on figure 5 (b). It was only possible, using traditional methods, to measure the final result over a restricted frequency range. It can be seen, however, that the mid frequency result approaches twice that of a 215 mm brick separating wall, indicating that a high degree of structural isolation has been achieved in this case. The 500 Hz value of 96 dB is approximately 25 dB better than achieved between the other pair of rooms.

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The adoption of isolated forms of construction can result in a very high degree of sound insulation but the result is highly sensitive to detailing and workmanship. The large difference in the achieved result between nominally identical pairs of rooms is difficult to explain.

CONCLUSION

Architects have a wide variety of constructional methods at their disposal to protect building users from internal noise. To ensure that appropriate methods are adopted, the functional requirement must first be established in consultation with the client. The client's brief must be translated into a numerical performance standard on the basis of which an appropriate form of construction can be selected. The chosen construction must be carefully detailed to ensure that all potential flanking transmission paths are minimised and the contractor must be required to achieve a high standard of workmanship on site to ensure a successful result in practice.

REFERENCES

[1] M West and PH Parkin, Applied Acoustics Vol 8 No 1 January 1985, The effect of furniture and boundary conditions on the sound attenuation in a landscaped office

[2] J Miller, Proc. IoA, Vol 8: part 1, pp 33 - 38, 1986, Sound insulation improvements to a dry-lined party wall

[3] J Miller and JG Charles, Proc. IoA, Vol 10: part 8, pp 129 - 136, 1988, Case studies in the sound insulation of music practice rooms

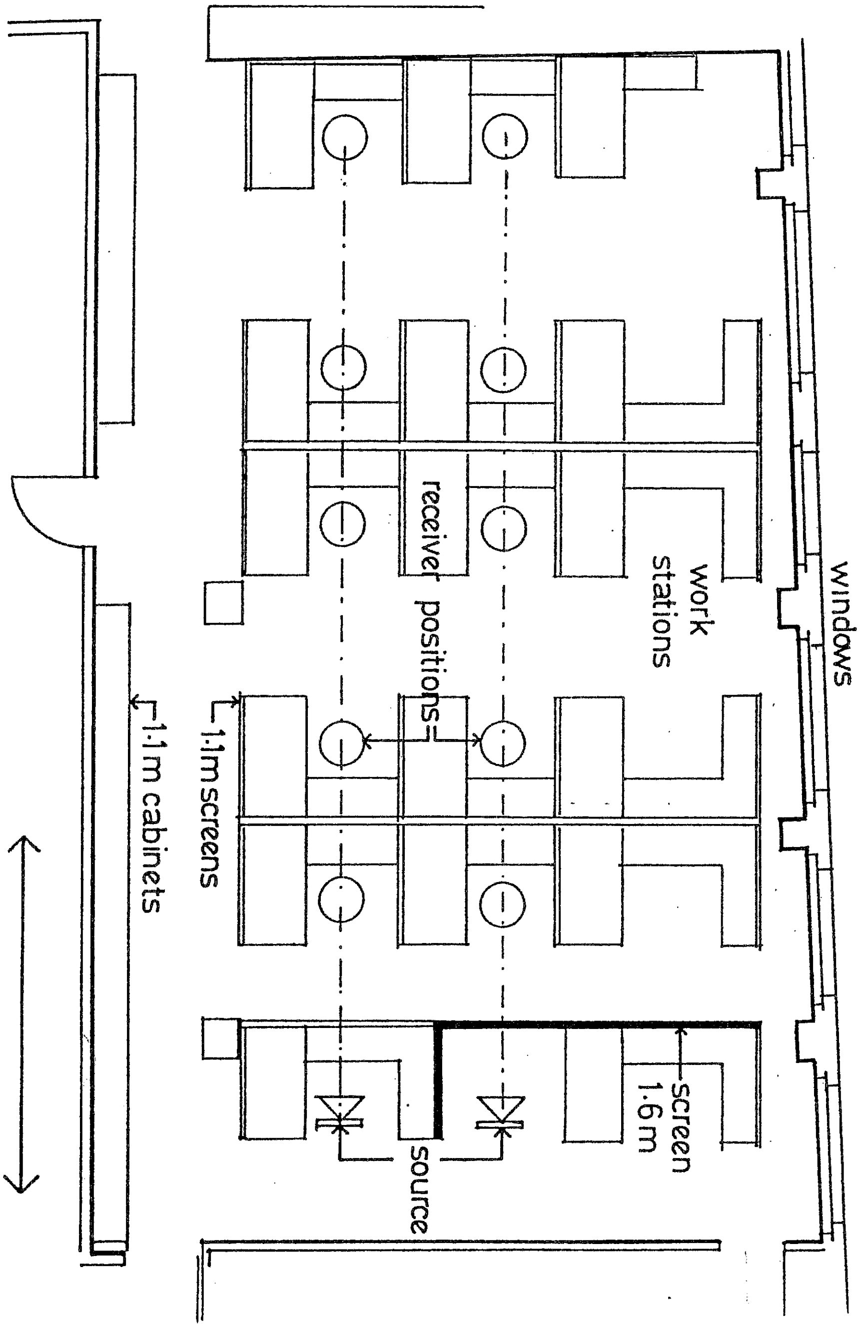

FIGURE 1: PLAN OF OPEN PLAN OFFICE

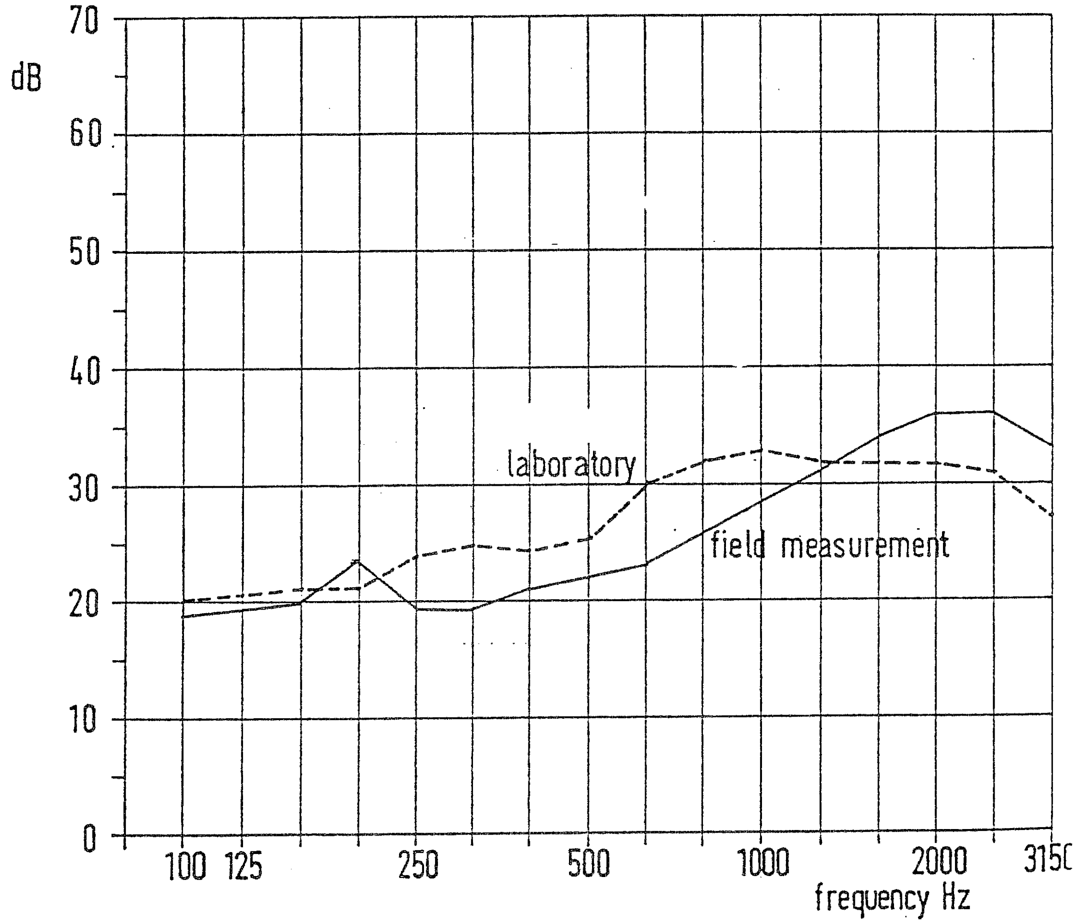

FIGURE 2: PARTITION SYSTEM, LABORATORY AND SITE MEASUREMENTS

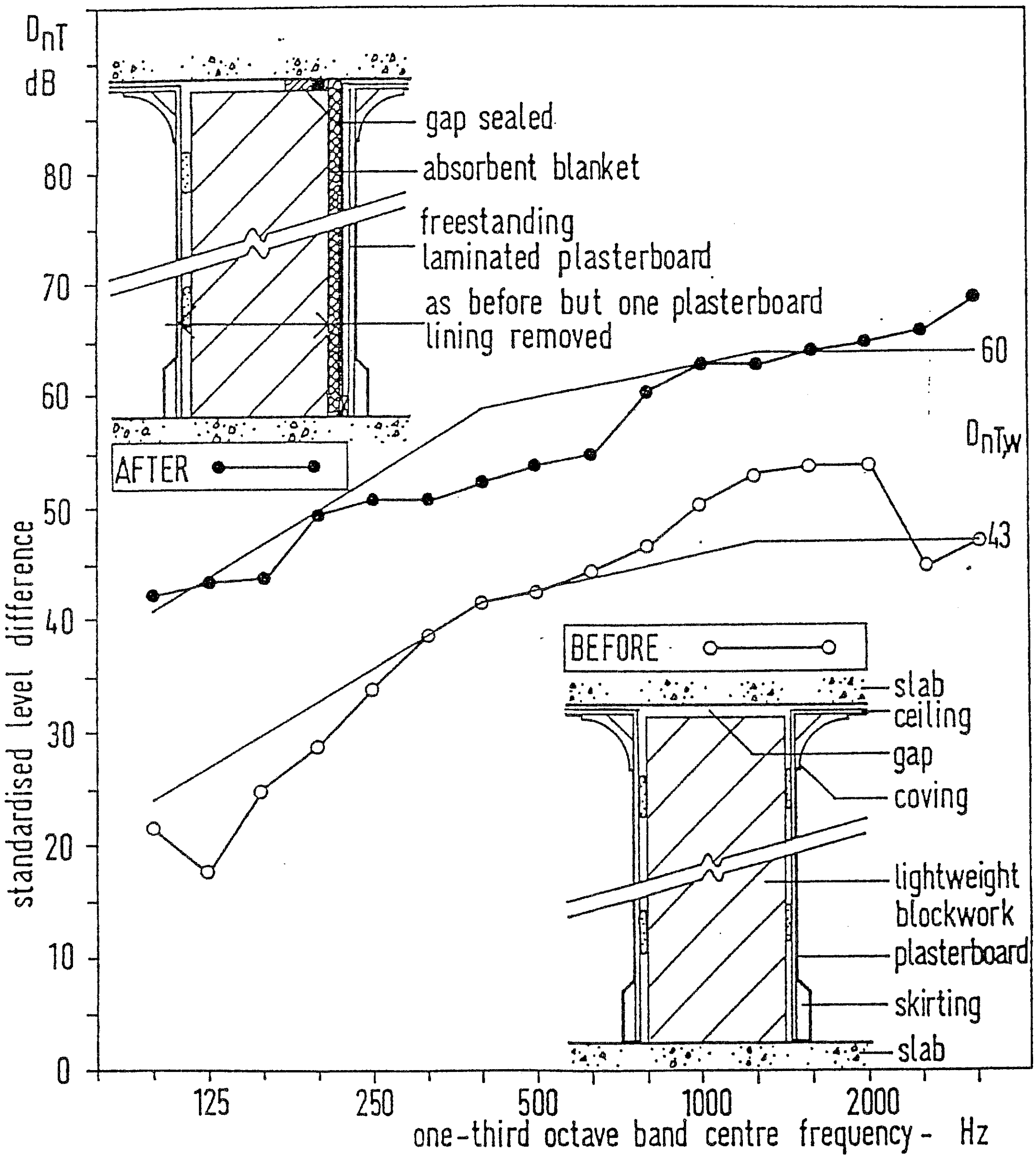

FIGURE 3: SOUND INSULATION IMPROVEMENTS TO A DRY-LINED BLOCKWORK SEPARATING WALL

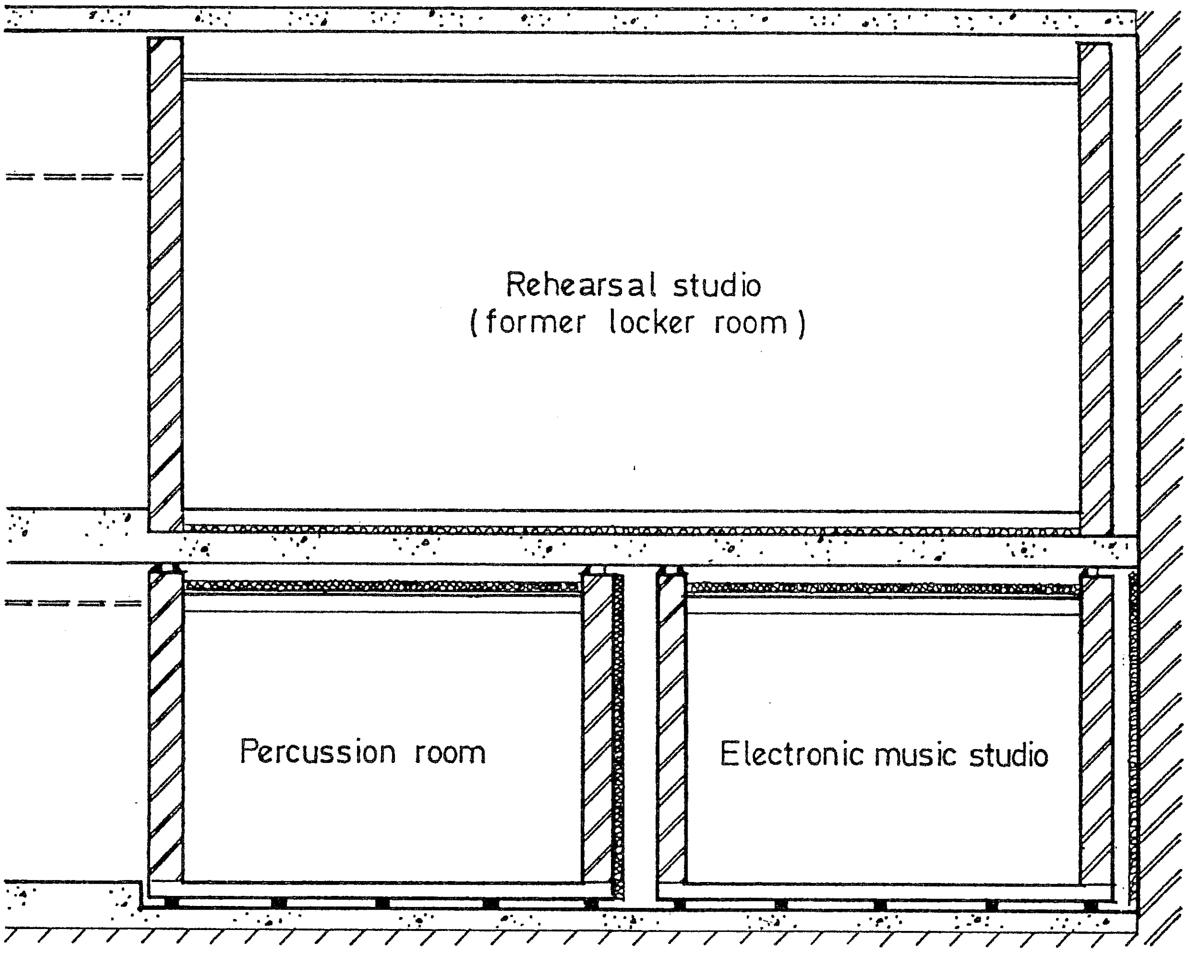

FIGURE 4: SECTION THROUGH ISOLATED MUSIC PRACTICE ROOMS

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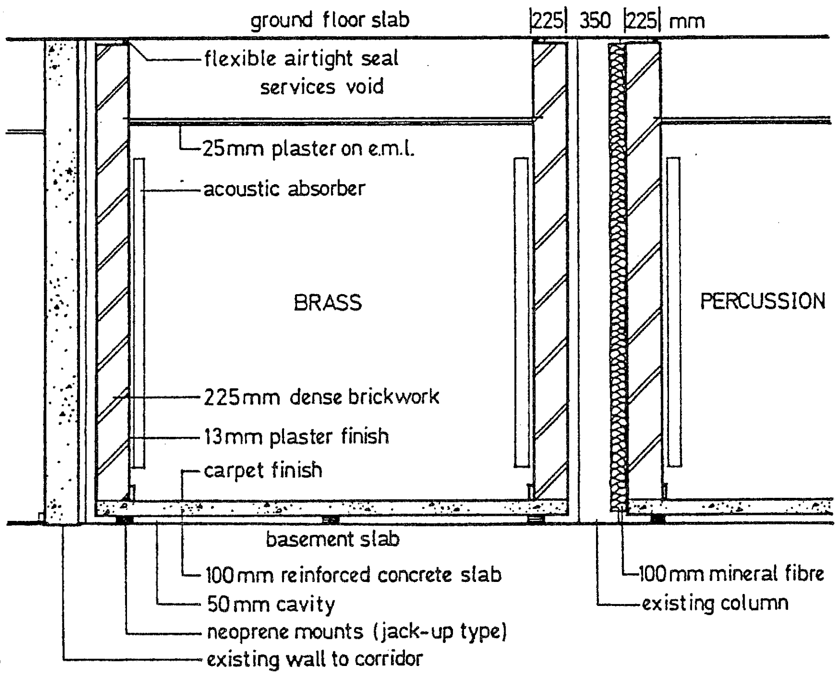

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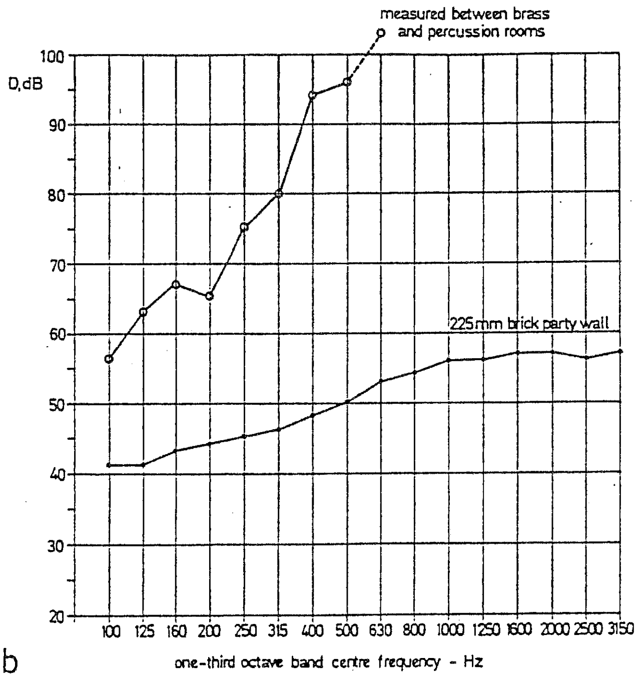

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FIGURE 5: SECTION THROUGH NEW ISOLATED PRACTICE ROOMS AND MEASURED LEVEL DIFFERENCE