SOUNDFIELD SYSTEMS IN CLASSROOMS

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1 INTRODUCTION

For a building to be sustainable, it must be capable of adaptation to meet different aspirations during its lifetime, whilst maintaining appropriate acoustic conditions. This paper considers the STI scores to be expected in classrooms, and examines whether the use of soundfield systems can compensate for the poorer levels of insulation caused by open-plan design and the inclusion of communicating doors between classrooms.

2 DETAILS OF THE MODELLED ROOMS

A pair of rooms were modelled with four standards of sound insulation between them:-

- a 140 mm medium-weight concrete block wall (48 dB weighted sound reduction index (R_W)), which would meet the 45 dB weighted normalised level difference ($D_{nT(Tmf,max),W}$) criterion in Building Bulletin 93 [1] for sound insulation between two classrooms ;
- a similar wall containing a 3.4 m^2 door with an R_W of 32 dB (reducing the partition R_W to 39 dB; this is also typical of the installed performance of a solid panel folding partition);
- a wall as in the first scenario, but only extending to 2.1 m (70% of the ceiling height), and
- no separating wall (i.e. a two-classroom open-plan teaching space).

The sound reduction indices of the partitions are listed in Table 1.

Material	Frequency (Hz)						
	125	250	500	1000	2000	4000	R_W
140 mm medium-weight concrete block	37.2	36.1	44.1	52.2	59.6	63.1	48
Acoustically rated double doorset	24.9	30.1	28.0	30.0	34.4	38.5	32
Wall and doorset combined	31.2	34.2	34.8	37.2	41.6	45.7	39

Table 1. Sound reduction indices (dB) for the party walls.

The rooms were modelled using the commercial acoustic ray tracing software *CATT Acoustic*. Each room was 8 m long by 6 m wide by 3 m tall, the separating wall between the rooms being 6 m by 3 m. The two rooms are identified in this paper as the “principal” room (in which speech intelligibility is being assessed) and the “competing room” (which acts as source of noise that may be transferred into the principal room).

Each surface in the rooms was assigned appropriate absorption and scattering coefficients, as listed in Tables 2 and 3. Furniture and other room contents were not modelled explicitly; the scattering coefficients of the walls were increased to 30% to take into account the scattering offered by the room contents. The resultant reverberation times in the rooms are predicted to be compliant with the mid-frequency average reverberation time (T_{mf}) criteria [1] for primary and secondary school classrooms (0.6 s and 0.8 s respectively). The average T_{mf} output by the model is 0.56 s, the maximum 0.7 s and the standard deviation 0.09 s.

Surface	Material	Frequency (Hz)					
		125	250	500	1000	2000	4000
Floor	Cord carpet	5	5	10	20	45	65
Walls	Plaster on concrete block	12	9	7	5	5	4
Ceiling	USG fissured regular tile in grid ceiling	27	32	33	43	53	61
Door	Timber door	14	10	6	8	10	10

Table 2. Sound absorption coefficients (%) for the surface finishes.

Surface	Material	Frequency (Hz)					
		125	250	500	1000	2000	4000
Floor	Cord carpet	30	30	30	30	30	30
Walls	Plaster on concrete block	30	30	30	30	30	30
Ceiling	USG fissured regular tile in grid ceiling	30	30	30	30	30	30
Door	Timber door	30	30	30	30	30	30

Table 3. Scattering coefficients (%) for the surface finishes.

Sound sources representing each teacher were located 2 m from the end walls of each room farthest from the party wall, with a height, directivity and frequency spectrum as specified in the Building Bulletin 93 guidance document for STI modelling [2]. This corresponds to an American National Standards Institute (ANSI) raised vocal effort.

Four loudspeakers were specified in each room for the soundfield systems; these were located at a height of 2.7 m on the side walls (spaced 0.2 m from the wall), and 2 m from the end walls. The speakers were aimed at the student's head height of 1.2 m (appropriate for secondary school pupils [2]) at a distance 2 m from the side walls. Directivity and frequency response information was measured at 30° intervals (interpolated to 15° intervals) both horizontally and vertically for a loudspeaker of similar type to those commonly used in soundfield systems (Figure 1). Measurements were made by playing pink noise through the loudspeaker and measuring the octave band spectrum at a distance of 1 m from the loudspeaker cone. The output from each loudspeaker was set to the spectrum for ANSI raised vocal effort (the same as the teacher source).

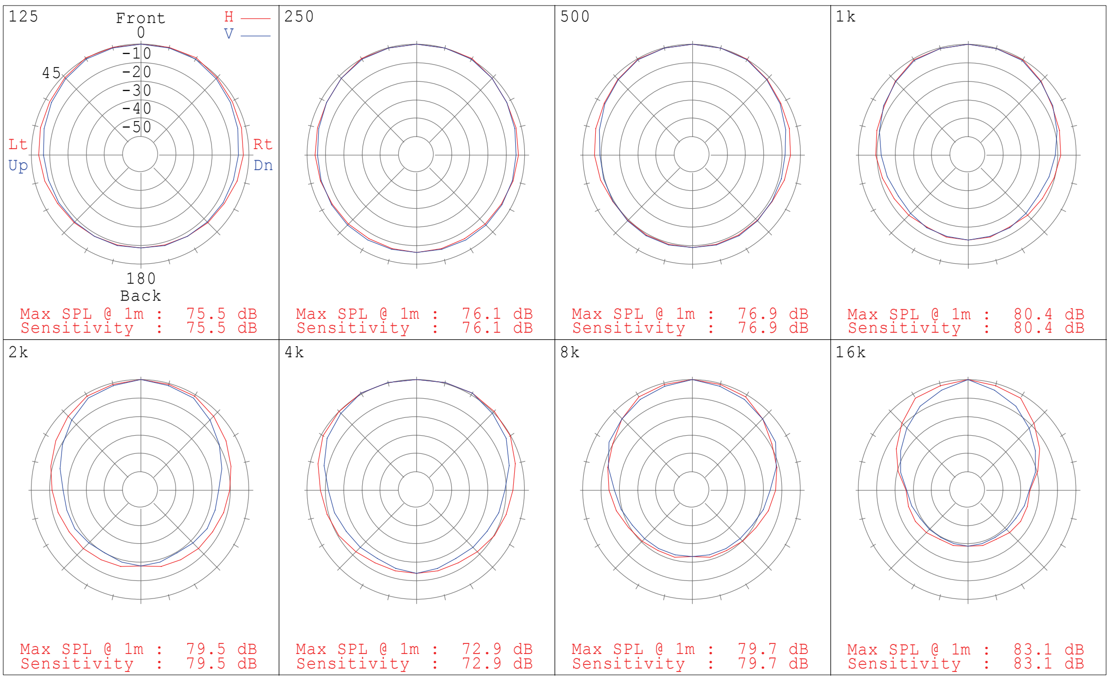


Figure 1. Directivity plots for the soundfield system loudspeakers, derived by measurement.

In order to assess speech intelligibility, the five sources in the competing room were defined as being noise sources. In addition, a "residual" background noise spectrum was defined to represent noise from the pupils in both rooms. This was assumed to be homogenous throughout the two spaces, with a sound pressure level of 52 dB(A) at 1 m and a spectrum as shown in Table 4. This level was determined to be appropriate for pupils working reasonably quietly in a classroom, both from site measurements and the typical sound levels tabulated in Building Bulletin 51 [3]. The shape of the spectrum was taken from site measurements. The disadvantage of this approach is that the transmission of background noise from the pupils in the competing room to the principal room is not modelled. However, the noise from this source is not dominant with the levels as modelled. It was confirmed that the simplified modelling of the ambient noise from the pupils had little effect on the results by placing a source next to the party wall in the competing room (with a sound pressure level of 52 dB(A) at 1 m) and mapping the increase in noise transmitted into the principal room. Even in the open-plan scenario, the maximum increase in total background noise levels in the principal room was only 0.4 dB(A) with the additional noise source.

Frequency (Hz)	125	250	500	1000	2000	4000	8000	16000
SPL (dB(A))	3.4	28.2	43.9	48.5	46.2	42.2	36.5	20.5

Table 4. Spectrum of the residual background noise, used to represent pupils within the space, from site measurements, scaled to give an overall level of 52 dB(A).

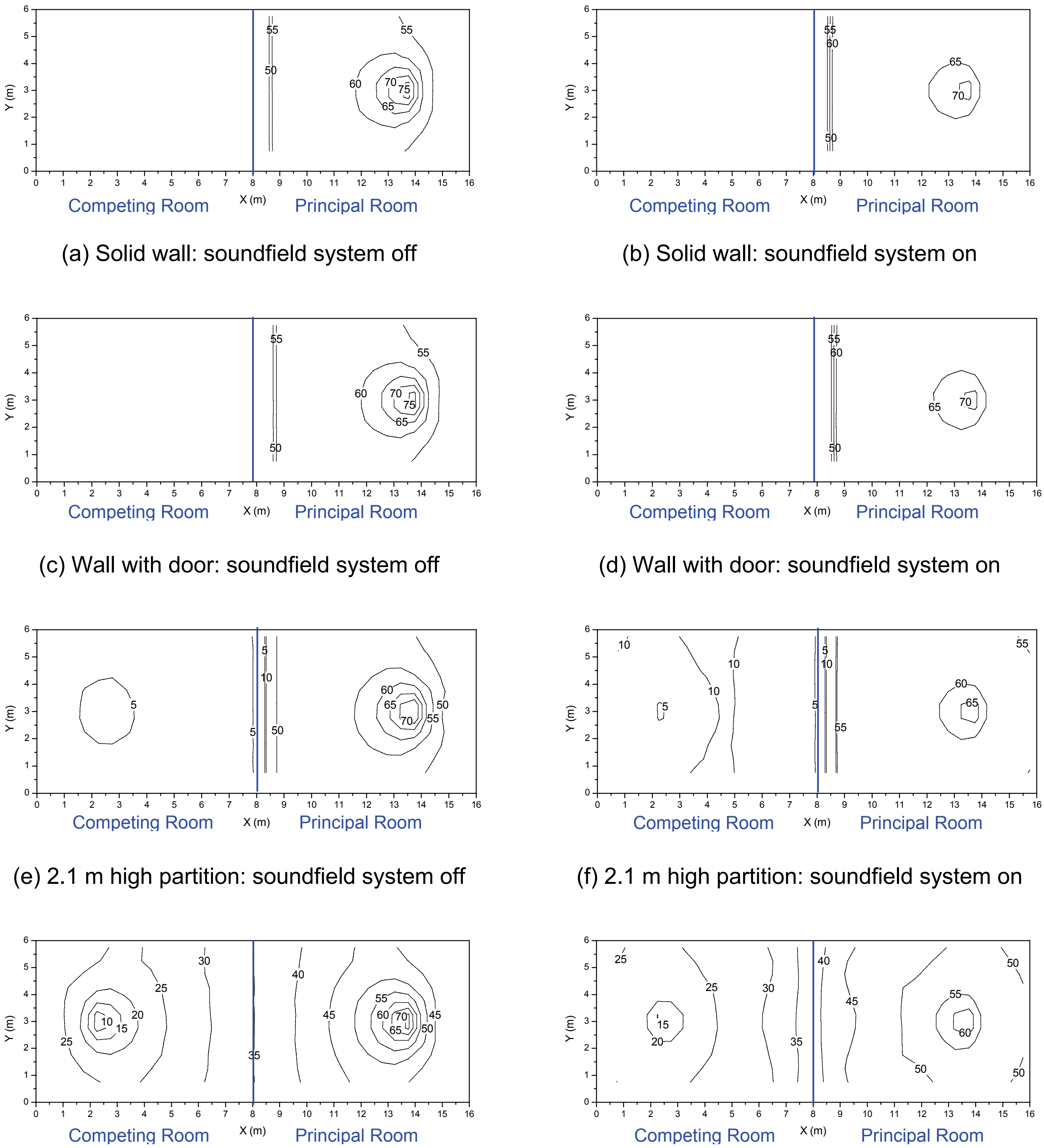
A further scenario was examined where the residual background noise level was reduced to 40 dB(A) to represent a very quiet classroom, and an additional noise source with a sound pressure level of 70 dB(A) at 1 m (and the same spectrum as the residual noise) was located 1 m from the partition wall in the competing room, to represent noisy activities in the competing room. The results from these simulations are discussed at the end of this section.

STI scores were predicted for each scenario using the Audience Area Mapping function in *CATT Acoustic*. The number of rays used was determined automatically by the software, and the ray adaptation option was used to significantly reduce the computation time. The ray truncation time was set to 3 s.

3 RESULTS

Figure 2 shows the predicted STI scores for the eight scenarios with the soundfield systems off in both rooms or on in both rooms, and a residual background noise level of 52 dB(A) in both rooms.

Figure 2a shows that even with an appropriately specified party wall between classrooms and compliant levels of sound absorption, the STI is predicted to fall below 0.6 at distances greater than 2 m from the teacher in the on-axis direction (0.6 forms the lower boundary of the range of values termed "good", and is the minimum value allowable under Building Bulletin 93 [1] for open-plan teaching spaces). At the rear of the classroom, the STI is predicted to fall to about 0.55. In this scenario background noise levels in the principal classroom are dominated by noise arising in the space, not noise transmitted into it from the adjacent room. The STI is therefore determined by the level of the speech signal compared to the level of noise from the pupils (and other sources such as building services and ICT equipment) in the space, and the reverberation time of the room.



(a) Solid wall: soundfield system off

(b) Solid wall: soundfield system on

(c) Wall with door: soundfield system off

(d) Wall with door: soundfield system on

(e) 2.1 m high partition: soundfield system off

(f) 2.1 m high partition: soundfield system on

(g) Open-plan: soundfield system off

(h) Open-plan: soundfield system on

Figure 2. Predicted speech transmission indices (plotted as percentages) at a height of 1.2 m for four scenarios of partition between the spaces, with and without a soundfield system in operation. In Figures 2a to 2d, the STI in the competing room is zero.

Figure 2b shows that with a soundfield system operational in both rooms, the STI scores are predicted to be appreciably higher in the principal room, remaining above 0.6 except at the extreme rear of the room (the results at the rear of the room should be treated with caution; the close proximity to a surface may be detrimental to the accuracy of the predicted values). This is despite the fact that the levels of noise transmitted into the principal room have been increased by the soundfield system operating in the competing room.

The results match well with measurements of signal levels made within classrooms with and without soundfield systems in operation [4]. Such measurements were made under unoccupied conditions, and the signal to noise ratio derived assuming a background noise level of 52 dB(A). STI scores were estimated from the signal to noise ratios and the reverberation times measured in the rooms using a graphical method [5]. Table 5 shows that the average and minimum STIs were significantly below 0.6 without a soundfield system in operation, even in the least reverberant rooms. With a soundfield system in operation, there were cases where an STI of 0.6 was exceeded throughout the room. Such results were obtained in the classrooms at Great Torrington Infants school, which is a new-build, with a highly sound-absorptive ceiling finish giving rise to a short reverberation time. A reduction in reverberation time from the 0.8 s allowable in secondary schools, or the 0.6 s permitted in primary schools, can have a significant effect on the STI when the signal to noise ratio is above zero.

School	Reverb-eration Time (T_{mf}), s	Soundfield System Off		Soundfield System On	
		Average STI	Minimum STI	Average STI	Minimum STI
Broadclyst Community Primary Room B	0.78	0.40	0.35	0.55	0.53
Countess Weir Combined	0.27	0.45	0.29	0.59	0.54
Ilfracombe Church of England Junior	0.60	0.40	0.33	0.47	0.44
Widecombe in the Moor Primary	0.48	0.44	0.33	0.49	0.44
Clyst Honiton Church of England Primary	0.60	0.46	0.40	0.53	0.50
Ditto, soundfield system "room noise" control set to high rather than Medium	0.60	-	-	0.62	0.60
Gt Torrington Bluecoat Infant & Nursery (old site) —Nursery	0.49	0.42	0.27	0.63	0.33
Gt Torrington Bluecoat Infant & Nursery (old site) —Classroom 13	0.50	0.48	0.38	0.69	0.66
Gt Torrington Bluecoat Infant & Nursery (old site) —Classroom 10	0.50	0.48	0.42	0.66	0.62
Gt Torrington Bluecoat Infant & Nursery (old site) —Classroom 16	0.50	0.41	0.28	0.66	0.58

Table 5. Average and minimum STI scores derived from measured signal levels, assuming a background noise level of 52 dB(A) [4,].

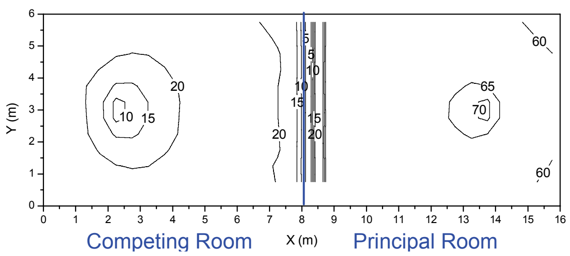
Figures 2c and 2d show the effect of reducing the level of sound insulation between classrooms on speech intelligibility (by 9 dB R_W). The STI results are unchanged. Noise levels transmitted into the principal room were increased from around 15 dB(A) to around 25 dB(A) owing to the poorer sound insulation. However, this source of noise remained significantly below the noise level assumed to arise in the principal room from the pupils (52 dB(A)), hence the negligible effect on the STI. Despite the levels of sound insulation being reduced in energy terms, the proportion of sound incident on the partition that is transmitted remains very low: a sound reduction index of 48 dB (as for the wall) implies that 0.0016% of the incident energy is transmitted; 39 dB (as for the wall with door) equates to 0.013% of the incident energy being transmitted.

Problems could still arise if high levels of noise occurred in the competing room at the same time as low noise levels occurred in the principal room. Such a scenario is considered later in this section.

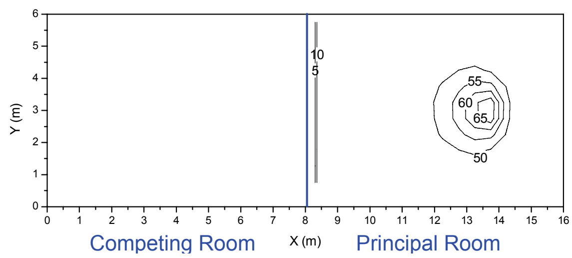
Figures 2e and 2f show that if the partition wall only extends to 70% of the ceiling height, leaving a 0.9 m gap, a significant degradation in the STI score results. The region in which an STI of 0.6 or greater is obtained (without soundfield systems) now only extends about 1.25 m from the teacher (on axis) and there is generally a degradation in STI score of about 0.05 in this scenario. With soundfield systems in operation, an improvement in the STI of about 0.05 is obtained distant from the teacher, negating the degradation due to the reduced-height wall. However, the STIs obtained close to the teacher remain poorer than if a full-height wall was provided. The levels of sound transmitted into the principal room from the competing room (about 57 dB(A) with the soundfield systems off and 60 to 62 dB(A) with them on) are now significant compared to the assumed

background noise levels of 52 dB(A) arising from the pupils in each space; this accounts for the degradation in STI.
Figures 2g and 2h show the predicted STIs in a double-classroom open-plan space. Whereas in Figures 2a to 2d the STI score is zero in the competing room (and in Figures 2e and 2f is 0.1 or less), in these two cases some intelligibility of sound from the principal classroom is sustained in the competing room, potentially causing significant disturbance. Without a soundfield system, the region in which an STI score of 0.6 or more is sustained now only extends about 1 m from the teacher (on-axis). Towards the rear of the principal room, STIs have fallen to below 0.4, compared to 0.55 with a full-height partition. With a soundfield system in operation in both rooms, the STI scores in the principal room are improved by about 0.05 (despite the levels of noise transmitted from the competing room to the principal room increasing from 61 dB(A) to 66 dB(A)), and still remain well below the 0.6 minimum requirement towards the rear of the principal room—and remain worse (by approximately 0.1) than in the rooms separated by a full-height partition without a soundfield systems in use. Introducing soundfield systems into the open-plan rooms has not increased the undesirable intelligibility of sound emanating from the principal room in the competing room, since the transmitted sound is masked by the separate soundfield system in operation in the competing room.

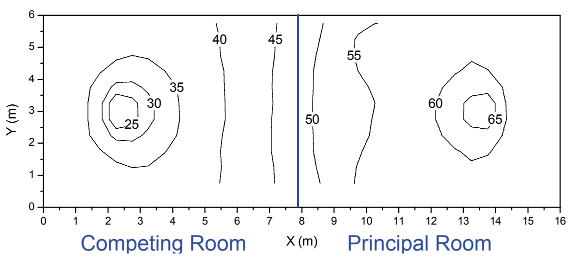
Simulations were also run with the soundfield system in use in only one of the rooms, to determine whether the equipping of only some rooms with soundfield systems could impair intelligibility in adjacent rooms owing to higher background noise levels. The resultant STIs are shown in Figures 3a to 3d. Since with a full-height partition in place noise from the competing room is not having a great influence on background noise levels in the principal room, the calculated STIs in the principal room remained unchanged from the previous scenarios with both of the soundfield systems switched off or switched on (*i.e.* the plots obtained are identical to Figures 2a to 2d).



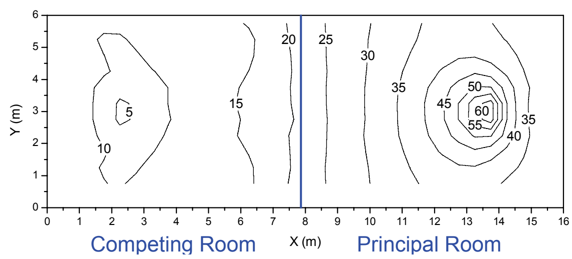
(a) 2.1 m high partition: soundfield system on in principal room only



(b) 2.1 m high partition: soundfield system on in competing room only



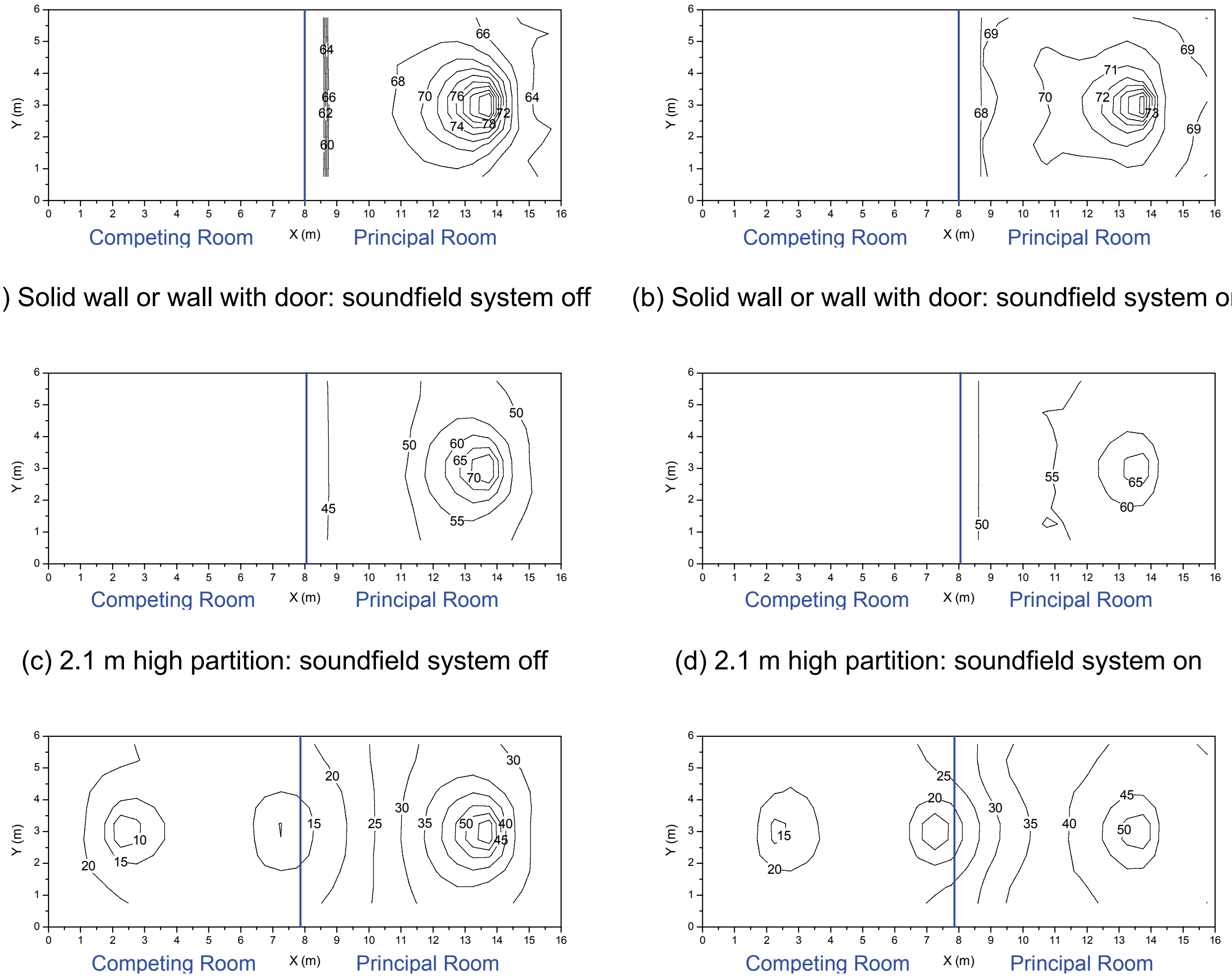
(c) Open-plan: soundfield system on in principal room only



(d) Open-plan: soundfield system on in competing room only

Figure 3. Predicted speech transmission indices (plotted as percentages) at a height of 1.2 m for the semi-open plan and open plan scenarios, with a soundfield system in operation in one room only.

The results for the 70% height partition and the open plan scenarios are, however, influenced by the presence of a soundfield system in one room only. With a 70% height partition, if the soundfield system is in operation in the principal room only (Figure 3a) an improvement in STI of about 0.05 is effected at the periphery of the room compared to the scenario with both soundfield systems in operation, and the results outperform those for classrooms separated by full-height partitions that are not equipped with soundfield systems. However, the corollary of this is that the STI scores in a classroom without a soundfield system and with a 70% height partition will be reduced if the adjacent classroom has a soundfield system (Figure 3b).



(a) Solid wall or wall with door: soundfield system off

(b) Solid wall or wall with door: soundfield system on

(c) 2.1 m high partition: soundfield system off

(d) 2.1 m high partition: soundfield system on

(e) Open-plan: soundfield system off

(f) Open-plan: soundfield system on

Figure 4. High competing noise scenario (70 dB(A) at back of competing classroom and 40 dB(A) in principal classroom): predicted speech transmission indices (as percentages) at a height of 1.2 m for four scenarios of partition between the spaces, with and without soundfield systems in operation.

For the fully open-plan scenario, with a soundfield system in the principal room only (Figure 3c), the STIs are improved by about 0.05 near the source and by 0.10 at the rear of the class, compared to the scenario with a soundfield system operational in both rooms (although they remain poorer than in classrooms with full-height partitions without a soundfield system, and values below the 0.6 criterion for intelligibility in open-plan teaching spaces still occur). The change can be explained by the reduction in noise in the principal room transmitted from the competing room. The STIs of sound from the principal room are increased by about 0.1 in the competing room, so this noise would now be more distracting to activities in the competing room. This is also evident in Figure 3d:

soundfield system in the competing room only: this results in a degradation in the STI of about 0.1 in the principal room, consistent with the results in Figure 3c.

The effect of a more demanding scenario for noise intrusion has been examined by reducing the assumed background noise from pupils to 40dB(A), representing very quiet activities, and adding a 70 dB(A) noise source in the competing room adjacent to the separating partition to represent noisy activities in that space. The resultant background noise levels (excluding the 40 dB(A) background noise present in both rooms) and STI scores are shown in Figures 4a to 4f.

Figures 4a and 4b show that with a full height partition, the STI actually increases under this new scenario (results are similar with and without a competing door present). The reason is that the increase in noise transmitted through the partition is more than compensated for by the reduced noise level arising in the principal room itself. This analysis does not take into account the distraction that even limited audibility of the noise in the adjacent classroom would cause. For the case with the 70% height partition (Figures 4c and 4d), the two considerations come close to balancing each other out, and the change in the pattern of predicted STI scores is slight. In the fully open-plan scenario (Figures 4e and 4f), the high level of noise transmitted from the competing room results in a significant degradation in the STI scores (by about 0.15 without soundfield systems in operation, and 0.1 with soundfield systems in use).

4 CONCLUSIONS

STI modelling has shown that without a soundfield system in operation, the STI in a classroom will fall below the 0.6 requirement set by Building Bulletin 93 for open-plan teaching spaces for much of the floor area. This is due to the influence of typical background noise levels within the room. With a soundfield system fitted, an STI of 0.6 or above can be achieved throughout the body of the room. These results correspond well with site measurement.

Providing a communicating door in the wall was not predicted to have a significant effect on the STI, increased background noise from the competing room being insignificant compared to that assumed to arise in the principal room. STIs were predicted to improve with reduced noise levels in the principal room and increased levels in the competing room (potentially a worst-case scenario), but in this case STI is not thought to truly represent the distraction that the noise could cause.

With a 70% height partition, disturbance from the competing room becomes significant compared to background noise in the principal room and STI scores suffer as a result. The problem becomes more acute in a fully open-plan scenario. In both cases, the STI score is improved significantly with soundfield systems in operation (but remains poorer than in cellular classrooms without soundfield systems). If a soundfield system is used in one of the class areas only, a significant degradation is experienced in the area that is not equipped with a soundfield system.

5 REFERENCES

1 Department for Education and Skills, 'Building Bulletin 93: Acoustic Design of Schools. A Design Guide', (2003).
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4 T.A.Mitchell, 'The Acoustic Performance of Temporary School Classrooms', Proc. I.O.A 28(1) 300-309. (2006).
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