Sound field of typical single-bed hospital wards

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ABSTRACT

There is a strong tendency that more single-bed wards are encouraged, especially in the UK National Health Service (NHS) hospitals. However, little research has been conducted to comprehensively examine the sound field of typical single-bed hospital wards. The aim of this paper is therefore to study the basic characteristics of sound fields in such spaces and the effects of commonly used furniture. The study also aims to investigate the feasibility and strategic use of acoustic simulation techniques for such spaces. Two typical single-bed wards at a Critical Care Unit were selected as the case study site. Eight different room acoustic conditions were created by gradually moving out pieces of furniture from the ward. It has been shown that under empty room condition the RT ranged between 0.8s, typically at low frequency, and about 2.3s at 630Hz in the ward without acoustic ceiling. The variations in both SPL and RT at different receivers were insignificant except at low frequencies, so that in such single-bed wards a diffuse field could be assumed. Longer RTs and higher SPLs were found when furniture was gradually moved out from the ward. With the acoustic ceiling, the effect of furniture was less. There is a good agreement between measured and simulated RT and SPL, with the commonly used surface absorption coefficients, showing the usefulness of computer simulation for this kind of spaces. The effect of surface diffusion coefficient is generally insignificant.

1. INTRODUCTION

Recently there is an increasing tendency that more single-bed wards are encouraged, especially in the UK National Health Service (NHS) hospitals, due to a number of advantages in terms of hospital costs, infection control and therapeutic impacts. The Health Building Note 04 recommends that 50% of hospital beds should be single beds rather than the traditional 10%[1].

In terms of creating a better cure environment, hospital units should be designed to reduce noise while retaining efficiency and effectiveness of operation. Although some studies have been carried out concerning hospital noise, most of them are only simple noise level surveys with limited acoustic indices considered. The effects of reverberation as well as sound reflection patterns have largely been ignored. Particularly, the sound field of typical single-bed hospital wards has not been systematically examined. The latest Health Technical Memorandum 08-01[2], which sets out acoustic criteria for the design and management of new healthcare facilities, does not have specified/detailed acoustic design targets, due to the lack of sufficient field acoustic measurements. Moreover, limited solutions are given to meet the acoustic criteria in

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this document. Furthermore, while in hospital wards it is commonly accepted that furniture affects the sound fields, there is little information on their absorption and diffusion coefficients, which are very useful at the design stage, especially for room acoustic simulation.

The main aim of this research is therefore to study the basic characteristics of sound fields in typical single-bed hospital wards, and the influence of commonly used hospital furniture on the acoustic environment. This research also aims to investigate the feasibility and strategic use of acoustic simulation techniques for such spaces, especially concerning the appropriate absorption and diffusion coefficients.

2. METHODOLOGY

A. Case study site

Noise in Critical Care Units (CCU) is always above the internationally recommended levels[3], while CCU patients are more likely to suffer from excessive noise exposure. Therefore a typical CCU, the Critical Care Department of the Northern General Hospital in Sheffield, was selected as the case study site. The dimensions of its single-bed wards were approximately 5.5m×4.8m×3m, as shown in Figure 1. Due to different levels of infection control, there were two types of ceiling, namely with and without absorbers, referred below in this paper as Ward A and Ward B, respectively. In Ward B eight different room acoustic conditions were considered by gradually moving out from the ward pieces of furniture including chairs, tables, computer, patient bed as well as medical equipment, as shown in Figure 2; whereas in Ward A only two extreme conditions were taken into account, namely empty and fully furnished, given that in Ward A the acoustic conditions were better due to the absorbent ceiling.

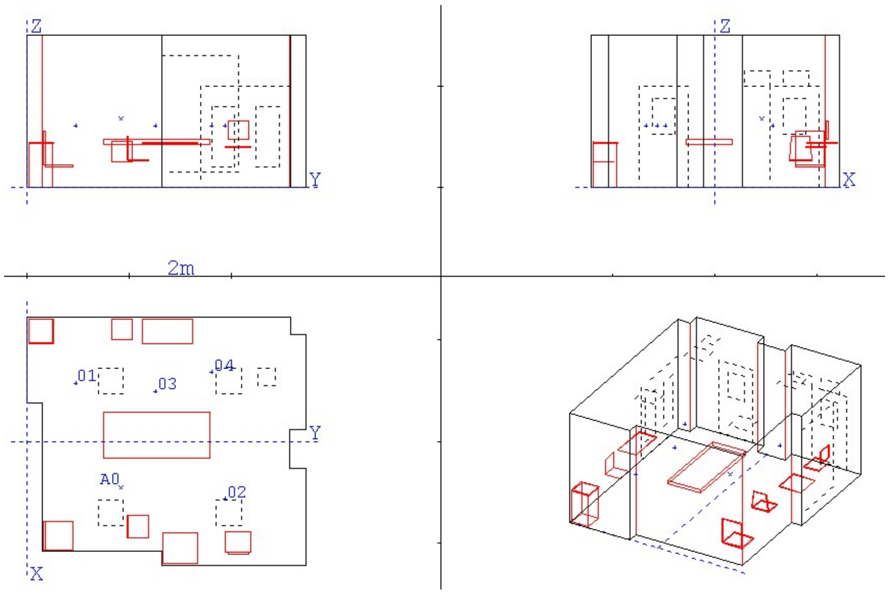

Figure 1: Ward B, where A0 indicates the omni-directional source, and 01-04 refer to the four receivers.

B. Measurement procedure

The measurements were taken when the wards were not in use, and during the measurement all the doors and windows in the wards were closed. The temperature and relative humidity were 25-28°C and 50-55%, respectively. Both reverberation time (RT) and sound pressure level (SPL) at four receiver positions were measured, using an omni-directional loudspeaker, placed at the common location of ward equipment at a height of 1.35m above the floor. The receiver height was 1.2m, which was the typical height when patients were in-bed. ISO 18233:2006[4] was followed in the measurement, and the measurement equipment used was the 01dB system.

Figure 2: Seven types of furniture in Ward B.

C. Computer simulation

Detailed comparisons were made in Ward B between the measured and simulated values by using acoustic software CATT-Acoustic (Version 8.0d). CATT is based on the combination of image source model for early part echogram qualitative detail and ray-tracing[5]. Given the relatively small size of the ward and the special features of furniture, it is important to validate the simulation results. For the empty room condition, the model built in CATT considered the elements of floor, wall, ceiling, window, door, ceiling light, ventilation grill and LCD glass. The initial diffusion coefficients were configured as 10% for all the surfaces.

3. MEASUREMENT RESULTS

A. Reverberation time

Figure 3 shows the measured RT of each frequency (125-4kHz) under eight different room acoustic conditions of Ward B, with gradual increase of furniture. It can be seen that, the bed is very effective in decreasing RT, with an average RT reduction of 40%, whereas any other piece of furniture only lead to a RT reduction of <12%. In order to further analyse the effects of furniture, the RT at 125-250Hz, 500-1kHz, 2-4kHz were averaged respectively, to represent the values at low, middle and high frequencies, as shown in Figure 4. It can be seen that the RT at both middle and high frequencies decreases continuously with increasing furniture, whereas at low frequencies the decrease in RT is less and there is also an increase by about 0.2s when the cabinet was placed in the ward. The main reason for this might be the room mode effects. In Figure 5 the effect of furniture in Ward A is shown by comparing the empty condition and fully occupied condition. As expected, the effectiveness is much less compared to that in Ward B. Also, in Ward B the RT decrease caused by furniture occurs mainly around middle frequencies, whereas in Ward A the decrease is relatively even across different frequencies. This is further demonstrated in Figure 6, where a comparison is made between Ward A and B in terms of the differences in RT between empty and fully occupied conditions.

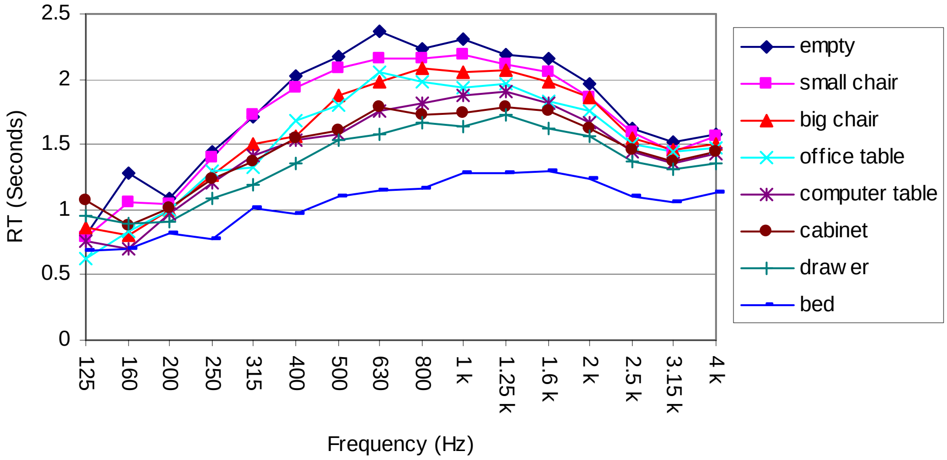

Figure 3: Measured RT in Ward B with gradual increase of furniture from empty to fully occupied condition (i.e. 'bed' in the figure).

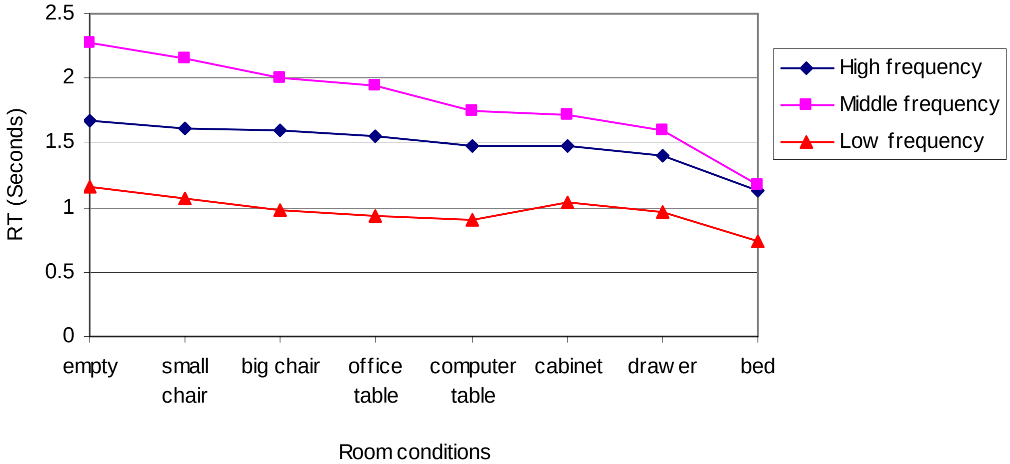

Figure 4: Measured RT in Ward B in low, middle and high frequency ranges with gradual increase of furniture from empty to fully occupied condition.

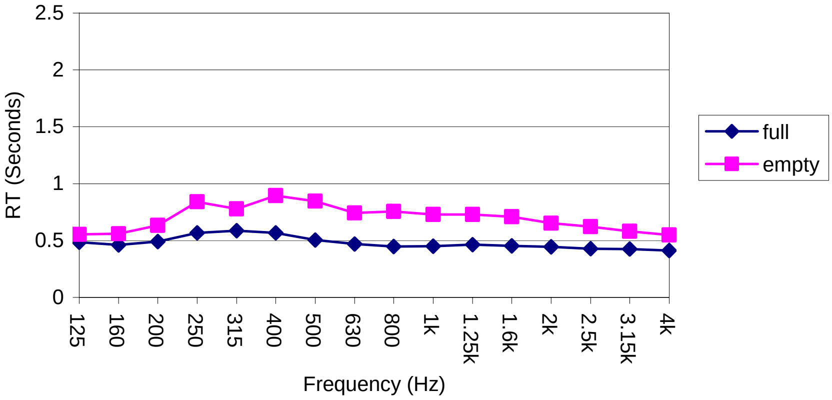

Figure 5: Measured RT in Ward A under two extreme room acoustic conditions: empty and fully occupied.

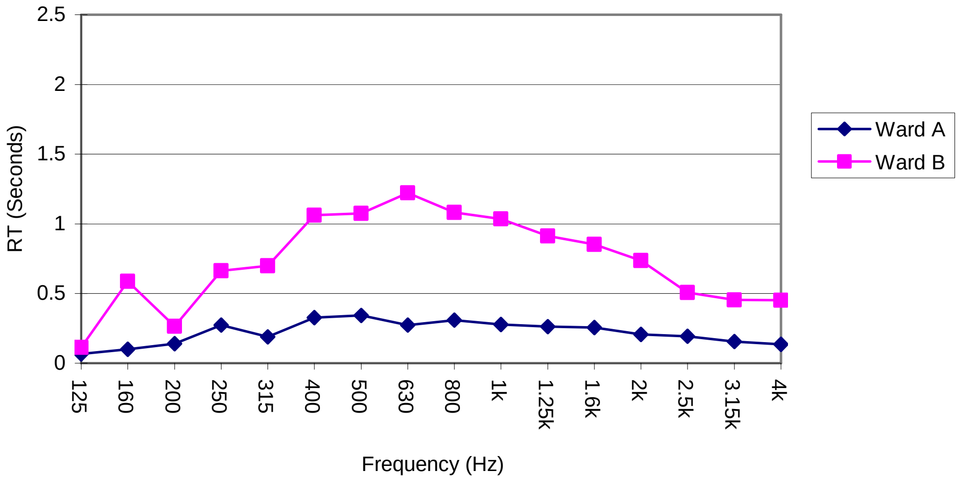

Figure 6: Comparison between Ward A and B, in terms of the differences in RT between empty and fully occupied conditions.

B. Sound pressure level

Figure 7 shows the differences in SPL between empty and fully occupied conditions at each receiver. It can be seen that the SPL under empty condition is 2-4dB higher than that under full occupied condition at middle frequencies, whereas at low frequencies the SPL difference varies significantly, as expected.

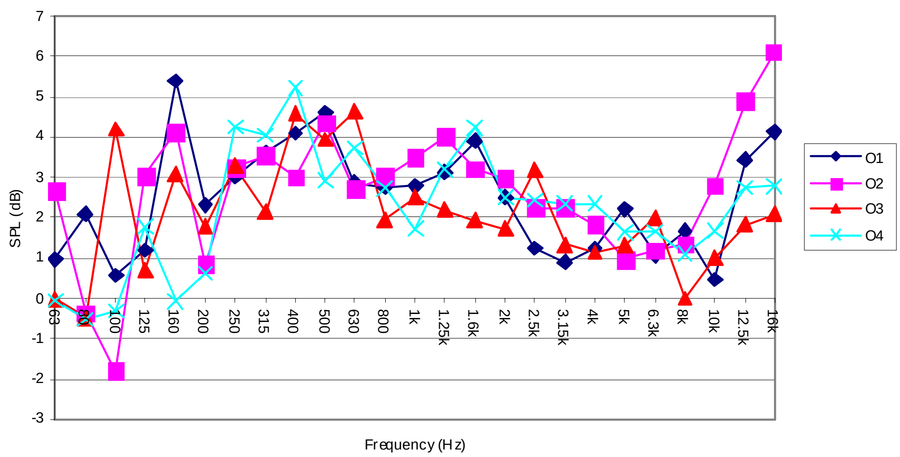

Figure 7: Differences in SPL between empty and fully occupied conditions at four receivers in Ward B.

Figure 8 shows the arithmetically averaged SPL at four receivers under eight room conditions in different frequency ranges, as well as at typical frequencies of 500, 1k and 2kHz. It can be seen that at lower frequencies the SPL fluctuation at four receivers is greater. Corresponding to the results in RT, when the bed is moved into the ward, there is also a significant decrease in SPL, especially at high frequencies. In terms of sound field evenness in this small ward, the standard deviation of SPL at four receivers is rather low, ranging from 0.25 to 0.50dB, as shown in Figure 9. This suggests that the ward could approximately be considered as a diffuse sound field. Again, in Figure 9 it can be seen that the standard deviation generally increases with decreasing frequency. The SPL at receiver 01 is relatively high, perhaps due to the short source-receiver distance and also the effect of strong reflecting surfaces.

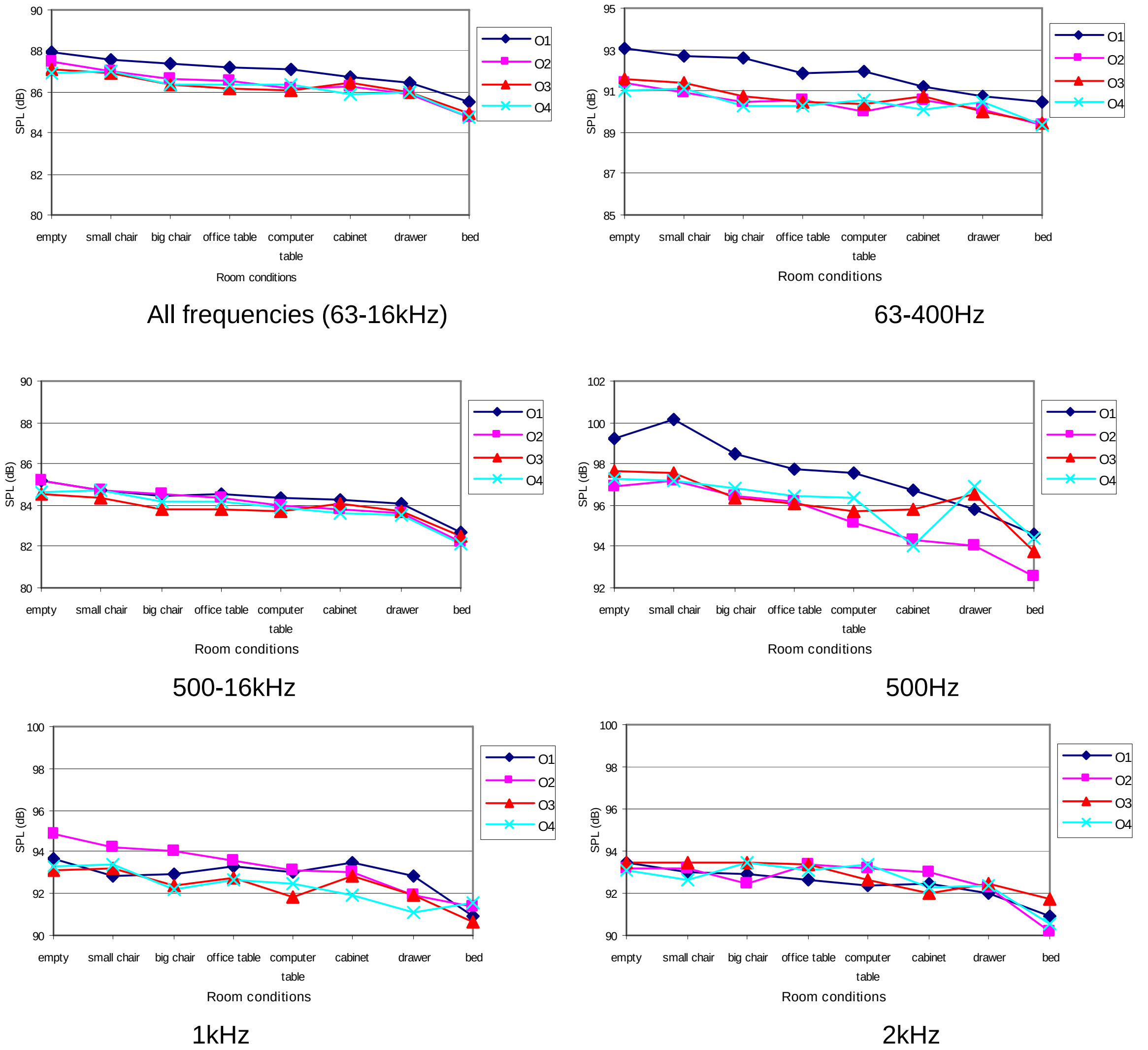

Figure 8: Arithmetic average SPL of four receivers under eight room conditions at different frequencies.

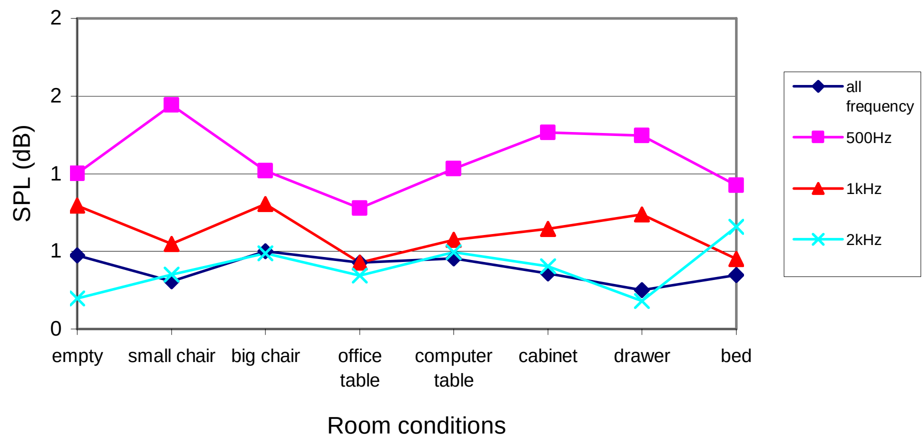

Figure 9: Standard deviation of SPL at four receivers.

4. SIMULATION RESULTS

A. Absorption

As different absorption coefficients have been reported in different publications for similar materials, a range of absorption coefficients were considered based on the literature and on-site estimation[6-8]. Table 1 lists the maximum, minimum and average absorption coefficients used in the simulation in this study, for the floor, wall and ceiling.

Table 1: *Absorption coefficients of floor, wall and ceiling based on the literature and on-site estimation.*

Surface		Frequency (Hz) 125	250	500	1k	2k	4k
Floor	Max	0.02	0.03	0.03	0.04	0.06	0.05
	Min	0.02	0.02	0.03	0.03	0.03	0.02
	Ave	0.02	0.03	0.03	0.04	0.04	0.04
Wall	Max	0.28	0.22	0.17	0.09	0.10	0.11
	Min	0.19	0.05	0.02	0.02	0.02	0.02
	Ave	0.23	0.12	0.08	0.05	0.05	0.05
Ceiling	Max	0.15	0.11	0.07	0.05	0.07	0.09
	Min	0.08	0.09	0.05	0.03	0.02	0.02
	Ave	0.12	0.10	0.06	0.04	0.05	0.05

As expected, if the maximum or minimum absorption coefficients are assigned to all the relevant materials, there are significant differences between the simulated and measured RT, as shown in Figure 10. However, if the average absorption coefficients in Table 1 are taken into account for all the surfaces, the agreement between simulated and measured RT under empty room condition is rather good, at 14.7%, 11.9%, and 4.0% at low (125-250Hz), middle (500-1kHz) and high (2-4kHz) frequency respectively.

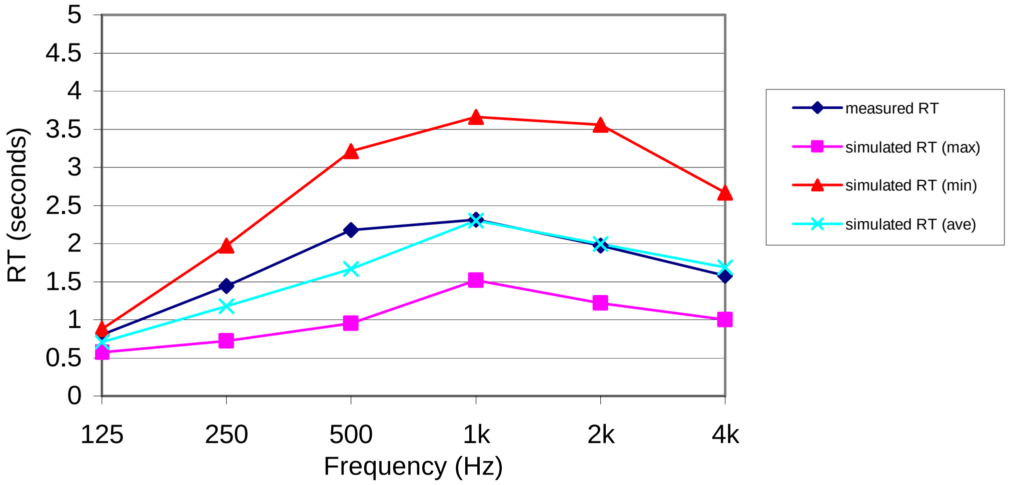

Figure 10: The comparison of measured and simulated RT under empty condition, considering maximum, minimum, and average absorption coefficients.

Table 2 compares the measured and simulated SPL under empty room condition, where the simulated data are normalised by adjusting the average SPL at four receivers to the measured value, since the source power level was unknown. In the simulation, the exponential filter was used, although between four filters the differences were insignificant. It can be seen that in terms of the standard deviation and the difference between the maximum and minimum SPL at four receivers, simulated values are systematically less than the measured values, at all frequencies.

Table 2: *Comparison between simulated and measured SPL(dB) under empty condition, with the standard deviation and the difference between maximum and minimum SPL at four receivers.*

	Frequency (Hz)	125	250	500	1k	2k	4k	8k
Receiver O1	Measured	94.9	102.8	99.2	93.7	93.5	86.0	78.3
	Simulated	93.4	100.5	97.7	93.7	98.5	86.1	77.7
Receiver O2	Measured	92.3	100.1	96.9	94.9	93.2	86.4	77.6
	Simulated	93.5	100.7	97.8	93.8	98.7	86.3	77.7
Receiver O3	Measured	91.7	98.7	97.7	93.1	93.4	86.0	77.5
	Simulated	93.5	100.5	97.7	93.7	98.5	86.2	77.8
Receiver O4	Measured	94.7	100.7	97.3	93.3	93.1	86.6	77.2
	Simulated	93.3	100.5	97.7	93.8	98.6	86.2	77.6
STD at 4 receivers, measured		1.65	1.65	1.69	1.00	0.79	0.20	0.34
STD at 4 receivers, simulated		0.10	0.10	0.10	0.05	0.06	0.10	0.08
Max-Min SPL, measured		3.26	3.26	4.08	2.30	1.77	0.38	0.69
Max-Min SPL, simulated		0.20	0.20	0.20	0.10	0.10	0.20	0.20

B. Surface diffusion

The effects of surface diffusion has been intensively discussed in literature[9-10]. While in the simulation presented above a surface diffuse coefficient of 10% is used, Table 3 compares the simulated RT and SPL with four diffusion coefficients assigned to all the surfaces: 1%, 10%, 20% and 100%. It can be seen that there are generally insignificant variations with different surface diffusion coefficients, for both RT and SPL.

Table 3: *Sensitivity of diffusion coefficient for RT (s) and SPL (dB) prediction under empty condition.*

		RT						SPL				
		125Hz	250Hz	500Hz	1kHz	2kHz	4kHz	O1	O2	O3	O4	Ave
Measured result		0.80	1.44	2.18	2.31	1.97	1.58	109.9	108.6	108.6	108.6	108.9
Diffusion coefficient in simulation	1%	0.85	1.23	1.73	2.37	2.07	1.73	108.8	108.9	108.8	108.9	108.9
	10%	0.71	1.18	1.67	2.30	1.99	1.69	108.9	109.0	108.9	108.9	108.9
	20%	0.69	1.18	1.66	2.29	1.98	1.69	108.9	109.0	109.0	108.9	108.9
	100%	0.70	1.20	1.68	2.30	1.99	1.69	109.0	109.2	109.2	108.8	109.1

5. CONCLUSIONS

Through the room acoustic measurements in two typical single-bed wards, it has been shown that under empty room condition the RT ranged between 0.8s, typically at low frequency, and about 2.3s at 630Hz in the ward without acoustic ceiling, whereas less varied RT was obtained in the ward with the acoustic ceiling, from 0.55 to 0.9s. The variations in both SPL and RT at different receivers were insignificant except at low frequencies, so that in such single-bed wards a diffuse field could be assumed.

As expected, longer RTs and higher SPLs were found when pieces of furniture were gradually moved out from the ward, indicating the significant influence of typical hospital furniture on the sound field. With the acoustic ceiling, the effect of furniture was less. Due to its high absorptive material, bed played a more important role in decreasing both RT and SPL, compared to other furniture in typical single-bed wards.

There is a good agreement between measured and simulated RT and SPL, with the commonly used surface absorption coefficients, showing the usefulness of computer simulation for such kind of spaces. The effect of the surface diffusion coefficient is generally insignificant, although the effects of edge diffraction/diffusion from various kinds of furniture are yet to be examined.

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