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ACOUSTICS IN LARGE ATRIUM SPACES

Jian Kang[1], Pau Ling Yap, Yan Meng, Bing Chen

School of Architecture, University of Sheffield
Sheffield S10 2TN, United Kingdom
j.kang@sheffield.ac.uk

Abstract

Many public buildings, such as shopping centres, airports, railway stations, hotels, and certain residential buildings, contain large atrium spaces, where the sound fields are usually not diffuse and thus the classic Sabine/Eyring theories are often inapplicable. This study aims to systematically examine the basic characteristics of sound fields in such spaces, and also to explore appropriate methods of calculating relevant acoustic indices. The acoustic comfort in such spaces and its relationships with the sound fields are also considered. In a number of typical large atrium spaces, objective measurements including reverberation as well as spatial and temporal sound distribution were made, and subjective evaluation of acoustic comfort were also carried out. It has been shown that with different source-receiver locations, the variation in reverberation is significant whereas the spatial sound distribution is relatively even. The Sabine formula could be used for predicting average reverberation time in the whole space, but for individual source-receiver positions computer simulation is essential. The acoustic comfort study suggests that the current acoustic conditions need to be improved.

1. INTRODUCTION

Large atrium spaces exist in many public buildings such as shopping centres, airports, railway stations, hotels, and certain residential buildings. In such spaces the volume is enormous, the surface conditions are complicated, and there are often a number of linked/coupled spaces. Consequently, the sound fields are usually not diffuse and the classic Sabine/Eyring theories are often inapplicable [1]. It is therefore of great importance to study the basic characteristics of sound fields in such spaces, as well as to explore appropriate methods of calculating relevant acoustic indices. Moreover, acoustic comfort is often a major concern in large atrium spaces, due to long reverberation and noise caused by a great number of users.

In this study, typical large atrium spaces have been studied, aiming at systematically examining the above issues. Figure 1 to 3 illustrate three selected case study sites, two in Malaysia and one in the UK, where objective measurements including reverberation time (RT) as well as spatial and temporal sound distribution were made, and subjective evaluations of the acoustic comfort were also carried out through questionnaire surveys.

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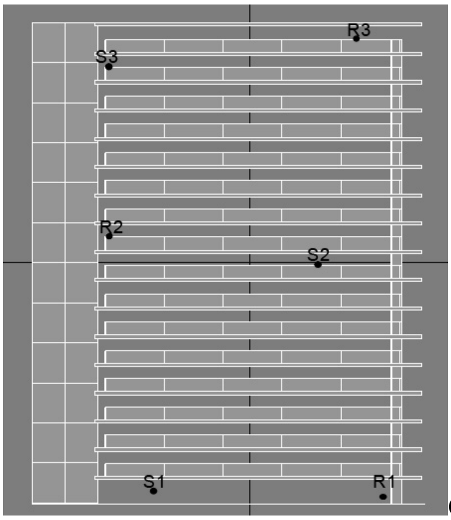
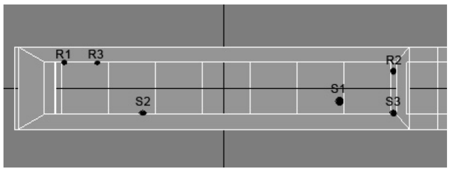
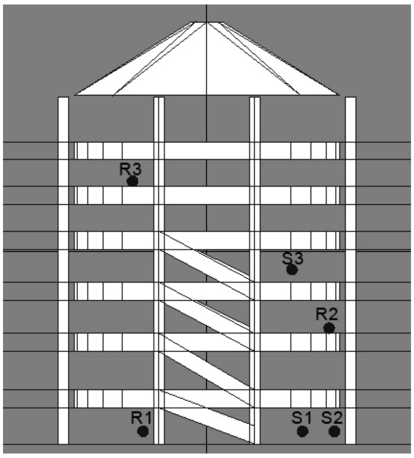
[1] Visiting Professor at the Harbin Institute of Technology.





CROSS-SECTION PLAN

Figure 1. Plan, cross-section and photos of the Pekeliling Flats, Kuala Lumpur, Malaysia.



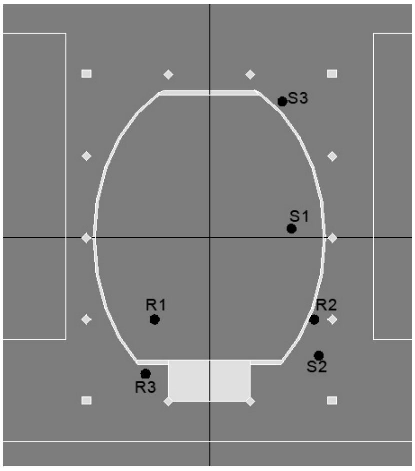
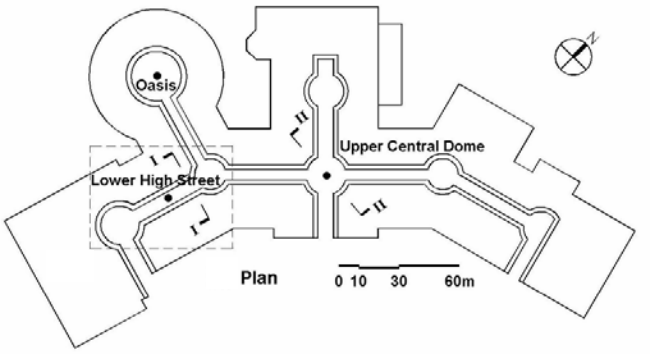
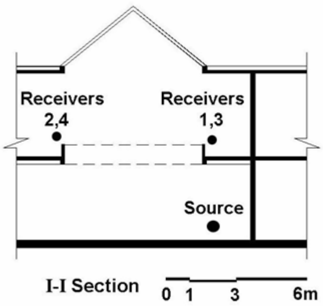


Figure 2. Plan, cross-section and photo of the One Utama shopping centre, Petaling Jaya, Malaysia.

OASIS





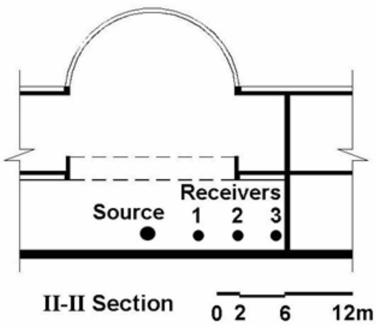


Figure 3. Plan, cross-section and photos of the Meadowhall shopping centre, Sheffield, UK.

2. ACOUSTIC CHARACTERISTICS OF LARGE ATRIUM SPACES

In the above atrium spaces, RT was measured using balloon popping at typical source and receiver positions (see Figure 1 to 3), the spatial sound pressure level (SPL) distributions were measured by playing white noise from a point source, and the temporal distributions of sounds from users/environment were measured in a number of typical days.

2.1 Reverberation and decay process

Figure 4 to 6 shows the measured RT. It can be seen that the reverberation is rather long in those spaces, typically at 3-5s, and the RT could vary considerably across frequencies due to the absorption characteristics of surface materials. For example, in Meadowhall the low frequency RT is relatively short, probably caused by the absorption from the glass panels. It is important to note that with different source-receiver positions the RT variation could be rather significant, for example, by about 50% with R3S2 compared to the mean RT in Figure 5.

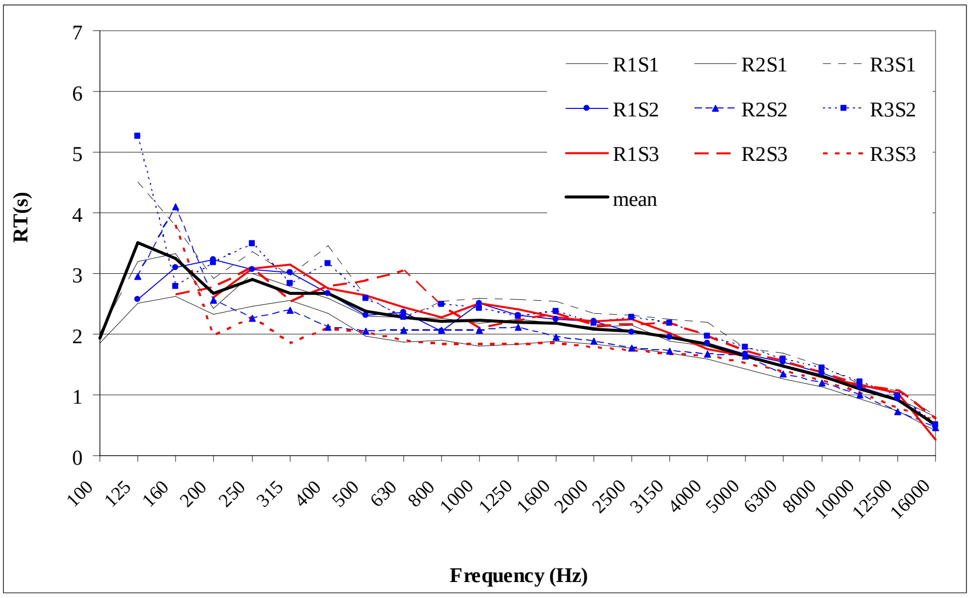


Figure 4. Reverberation times in the Pekeliling Flats with various source and receiver positions.

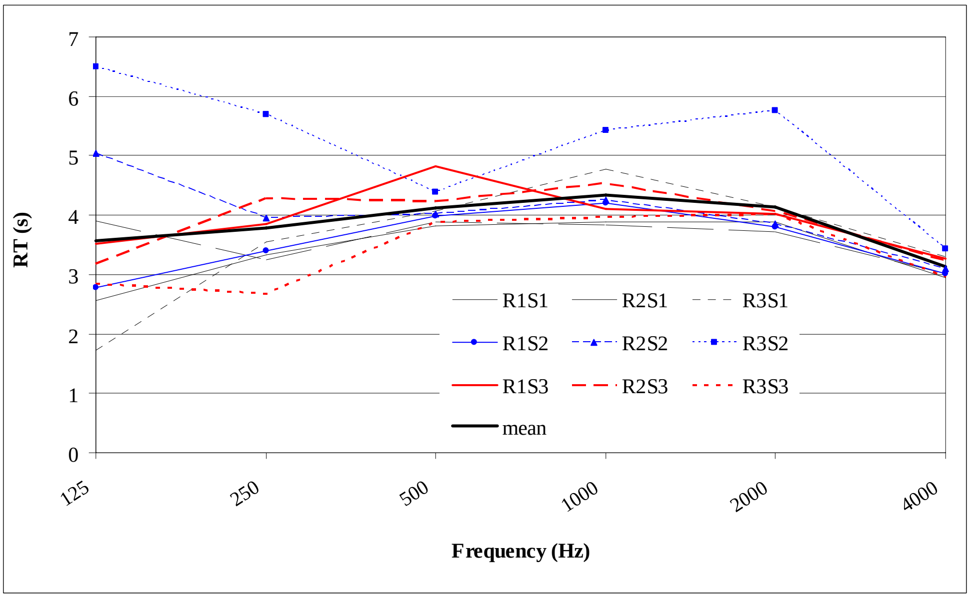


Figure 5. Reverberation times in the One Utama with various source and receiver positions.

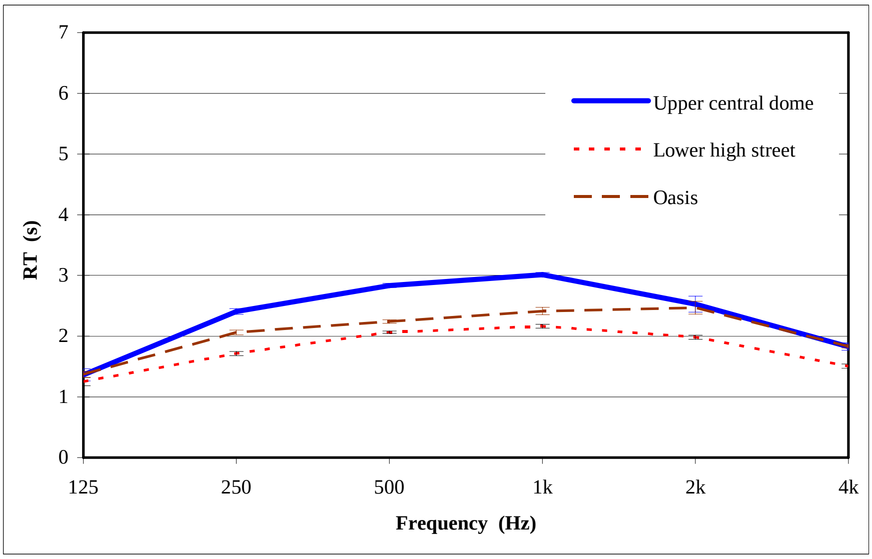
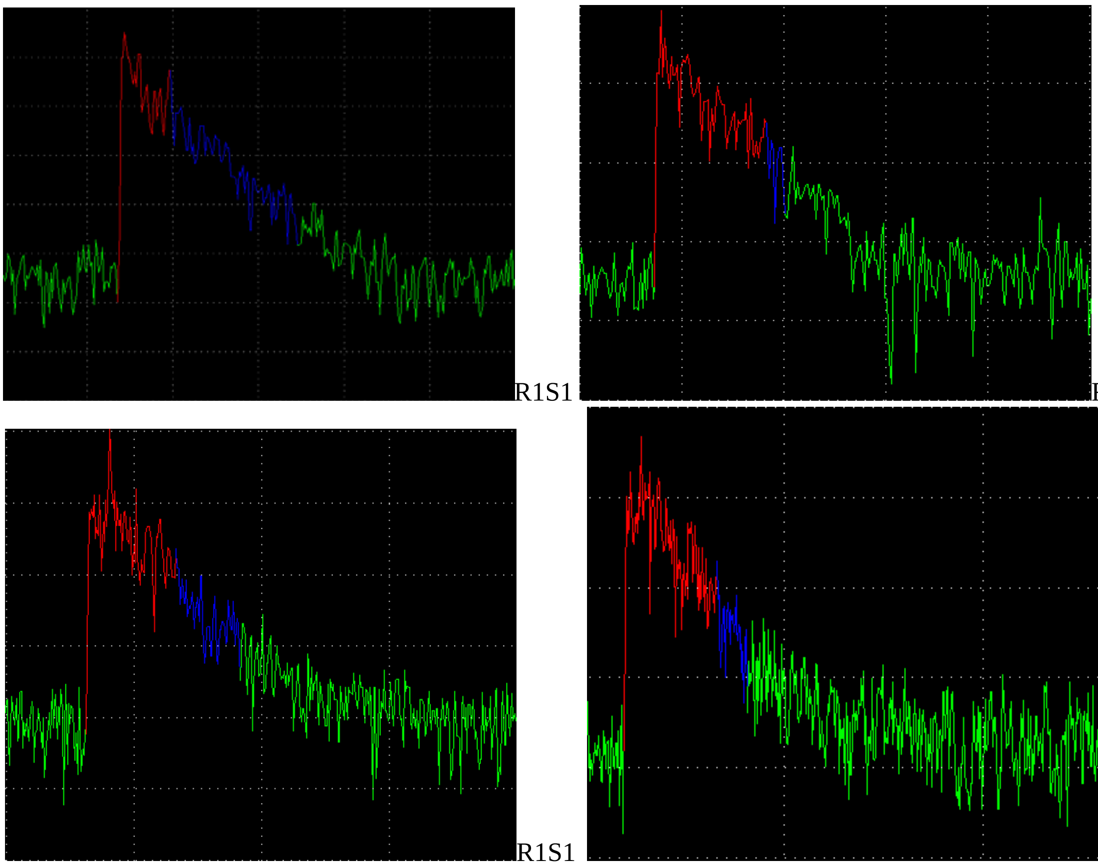


Figure 6. Reverberation times in the three atrium spaces in Meadowhall. The standard deviations between various receivers with a given source position are shown as error bars.

To further examine the characteristics of reverberation in such spaces, typical energy impulse responses are shown in Figure 7. It can be seen that the decay process is generally not linear in such spaces. Compared with the Pekeliling Flats, in the One Utama the decay process is extremely non-linear, probably caused by a large number of smaller spaces coupled with the main space. Within each space, the linearity of decay process also varies with different source-receiver positions. In the One Utama, the long RT with R3R2, as shown in Figure 5, might be caused by the curved decay process, which can be seen in Figure 7b.



(a) R1S1 R3S1

(b) R1S1 R3S2

Figure 7. SPL impulse response with typical source-receivers. (a) Pekeliling Flats, (b) One Utama.

2.2 Spatial sound distribution

Compared with RT, the spatial variations in SPL is relatively less, probably due to the effects of reflected energy, corresponding to the long reverberation as shown in Figure 1 to 3. In Figure 8 the SPL distribution with various source-receiver positions are shown. Further calculations indicate that the SPL variation at receivers R1-R3 is within 3dBA with source position S2 or S3, and about 8dBA with S1. This suggests that in such an atrium space, the sound disturbance between various parts would be rather significant.

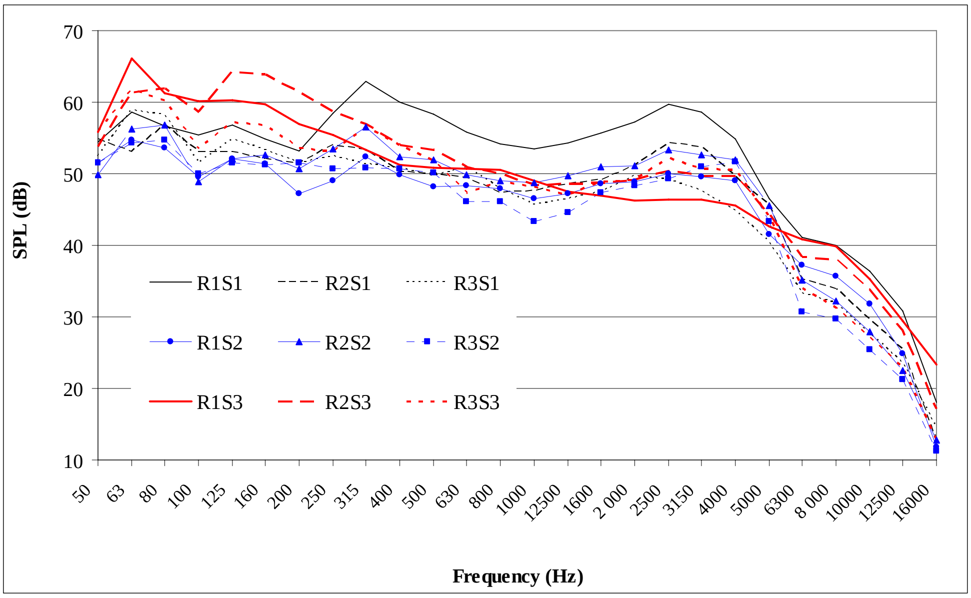


Figure 8. Spatial SPL distribution in the Pekeliling Flats with various source and receiver positions.

2.3 Temporal sound distribution

Figure 9 shows the temporal SPL fluctuations in Meadowhall [2]. It can be seen that the SPL in such spaces could be rather high, up to 80-85dBA. It is also interesting to note that there are considerable variations between different days and different times of a day, by 5-10dBA.

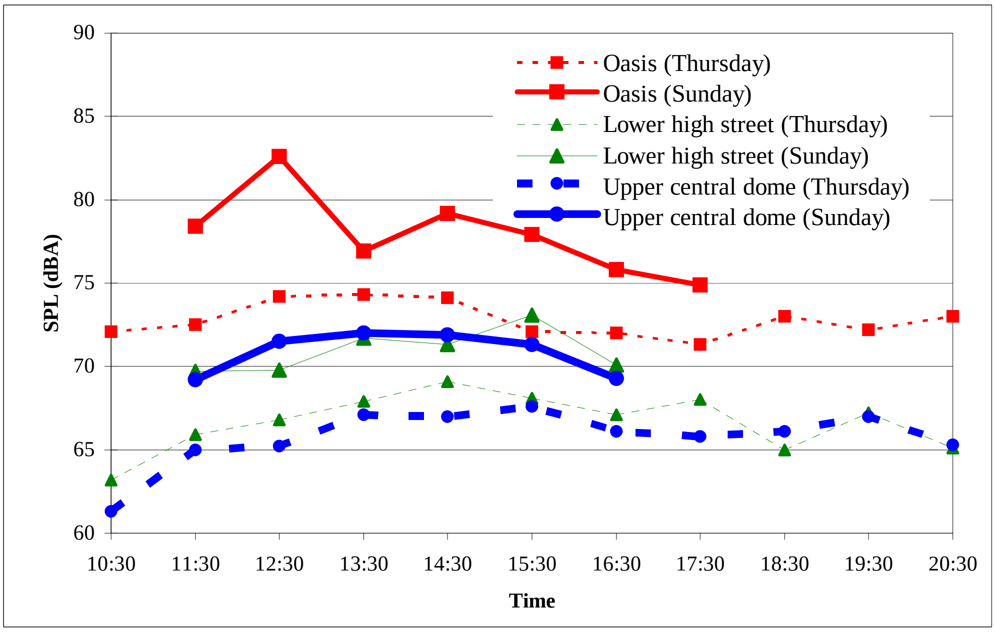


Figure 9. Temporal SPL fluctuations in the three atriums in Meadowhall on a Thursday and a Sunday.

3. COMPARISON BETWEEN CALCULATION AND MEASUREMENT

3.1 Classic formula

Given the non-diffuse characterises of large atrium spaces, it is of importance to examine the applicability of classic Sabine/Eyring theories. For the atrium space in the Pekeliling Flats, the absorption coefficients of the concrete boundaries and windows/doors, two main components in the space, were determined with the best-fit values through comparing the measured RT based on the average of five source-receiver positions (R1S1, R1S3, R2S2, R2S3, R3S2) and the calculation using the Sabine formula [3]. By using those absorption values, comparisons were then made between measurements at the other four source-receiver positions and the Sabine calculation, as shown in Figure 10. It can be seen that in terms of the average value at the four source-receiver positions there is a good agreement between calculation and measurement, whereas if the individual source-receiver positions are considered, there are notable disagreements, by 15% at R3S1 and 23% at R3S3, in average across frequencies.

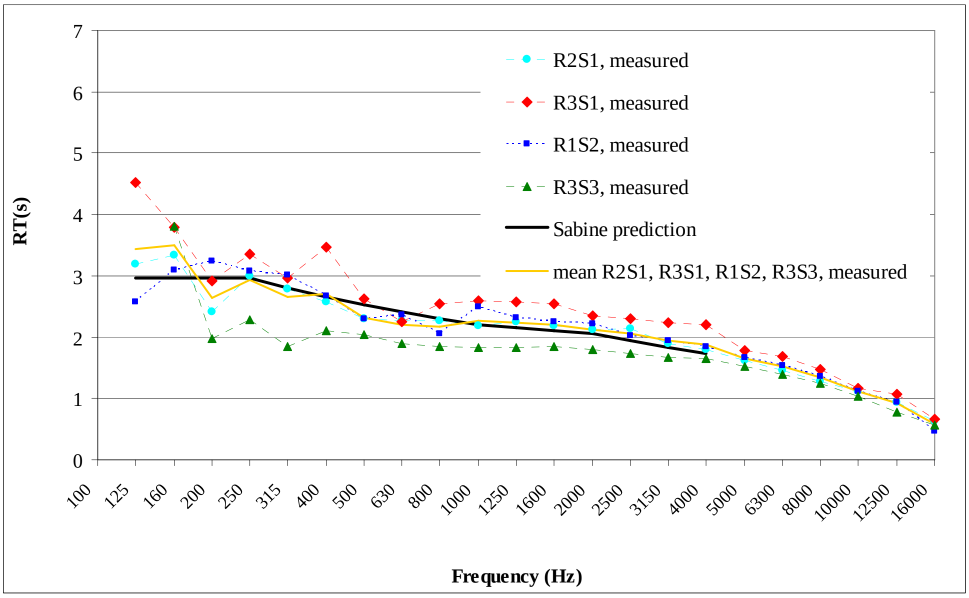


Figure 10. Comparison between measured reverberation time and calculation using Sabine formula.

3.2 Computer simulation

Since the classic theories can only predict average RT values in a whole space, it is essential to use computer simulations to consider individual source-receiver positions. A computer model, CRR, has been developed based on combined ray-tracing and radiosity methods [4,5]. This model is particularly suitable for atrium spaces since it can consider complicated boundary conditions with diffusion. The geometry object is divided into a set of patches, and then the system puts all geometry patches into a hierarchical acceleration data structure - kd-tree. This data structure makes ray intersection searching extremely fast. Each time a ray hits a surface, the specular energy is reflected to the next ray direction, and the diffuse energy is stored into this surface. After the ray-tracing process, the radiosity starts energy exchanges between patches. With a similar procedure as described in Section 3.1 but also considering the effect/sensitivity of boundary diffuse coefficients [3,4], comparisons between measurements and simulations using the CRR model were made, as shown in Figure 11. It can be seen that the model can predict RT well at all individual source-receiver positions including R2S1, R3S1, R1S2 and R3S3, within an accuracy of about 12%, in average across frequencies.

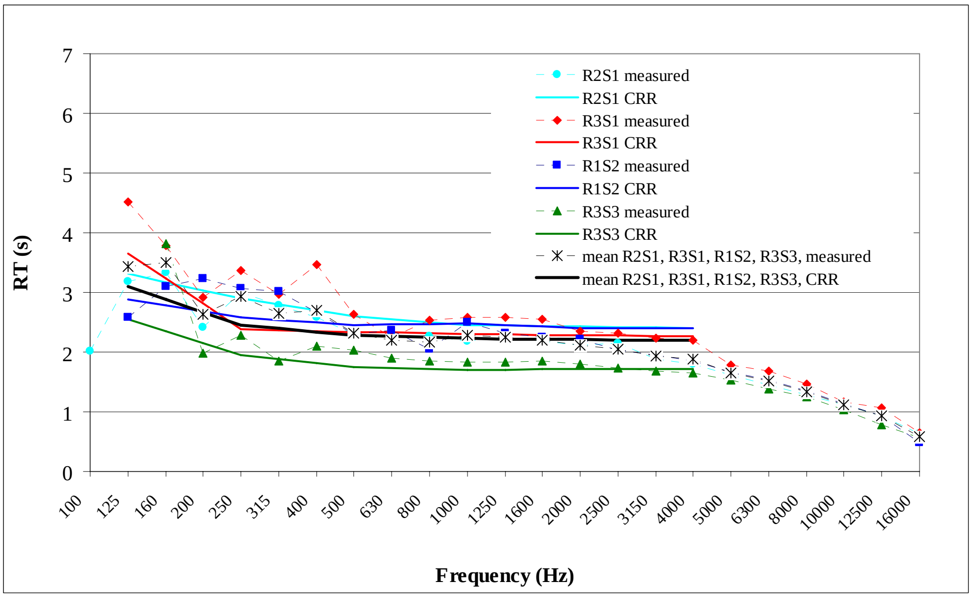


Figure 11. Comparison between measured reverberation time and simulation using the CRR model.

4. ACOUSTIC COMFORT

In the atrium spaces, a number of questionnaire surveys and semi-structured interviews were carried out among randomly sampled customers and staff members, where issues considered included general personal background, activities, evaluation of the acoustic environment in the space, description and evaluation of various sound sources in the space, evaluation of general environment quality in the space and additional comments. In this section the subjective results in Meadowhall are briefly discussed [2].

In terms of the acoustic comfort evaluation, generally speaking, no significant correlation was shown between age groups and between females and males. It is interesting to note that the acoustic evaluation might be affected by the duration of stay, the activities, and the acoustic condition at the people's homes, although such effects are generally not statistically significant in this case study. As expected, significant differences have been found between the acoustic sensitivities to different sounds – sounds from fountains are considered the most pleasant and sounds from nearby people are the most annoying.

There is a tendency that the overall acoustic comfort evaluation becomes less satisfactory with increasing SPL, but the correlation coefficient is rather low due to the complicated features of the various sound sources. Figure 12 shows the relationship between the measured SPL and the mean overall acoustic comfort rating, where 1, very uncomfortable; 2, a little uncomfortable; 3, neutral; 4, a little comfortable; 5, very comfortable.

In terms of speech intelligibility, the survey results suggest that there is a good correlation between the communication quality and the early decay time (EDT). In general, people feel less unsatisfied with the communication quality than with the overall acoustic comfort. It is interesting to note that the staff group are more tolerant in terms of communication comfort than customers.

On the whole, people are not satisfied with the current acoustic environment in Meadowhall. For a large and enclosed multi-functional shopping atrium with a high capacity, such as the Oasis, it would be important to reduce reverberation and noise level. For a typical long shopping atrium with most occupants staying for a relatively short term, such as the Lower High Street, introducing masking sounds like music and fountains would be effective for improving the acoustic comfort. For the Upper Central Dome, both types of treatment would be useful.

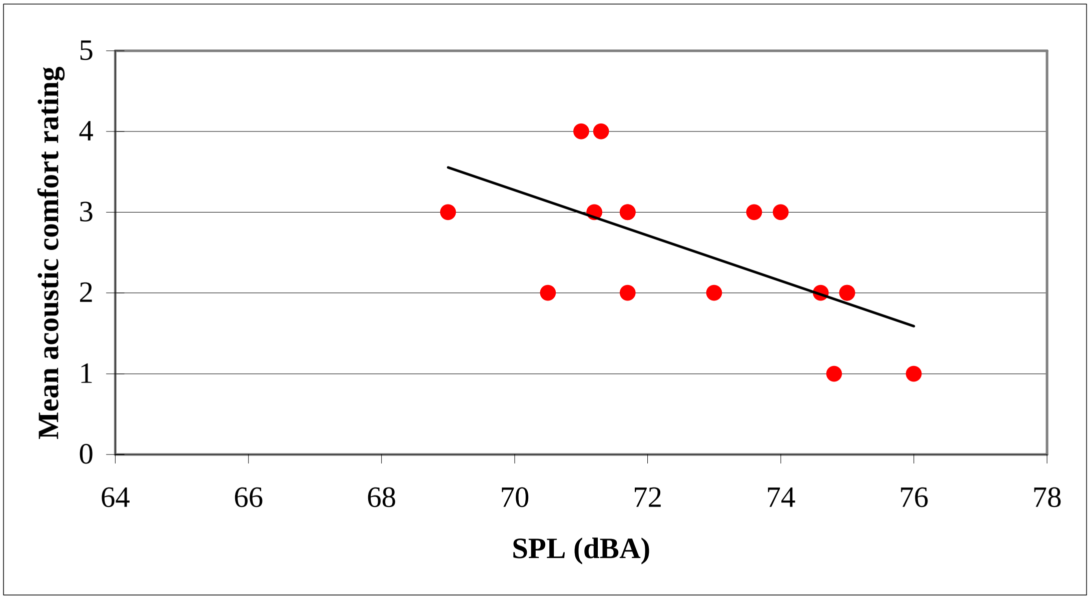


Figure 12. Relationship between the measured SPL and the mean overall acoustic comfort rating.

5. CONCLUSIONS

The measurement results show that the reverberation times in large atrium spaces are rather long, typically 3-5s, and the decay process is generally non-linear. With different source-receiver positions the variation in reverberation is significant, whereas the spatial sound distribution is relatively even.

The Sabine formula could be used for predicting the average reverberation time in the whole space, but for individual source-receiver positions computer simulation is essential and CRR model has been proved to be a useful tool for large atrium spaces.

The acoustic comfort study reveals the importance of considering and improving the acoustic conditions in typical existing large atrium spaces, and the importance of considering various social/demographic factors of the users when designing the acoustics of large atrium spaces.

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