Sound field and soundscape in underground shopping streets

Zhengzheng Tang[a]
School of Architecture
Harbin Institute of Technology
Harbin, P R China

Jian Kang [b]
School of Architecture
University of Sheffield
Sheffield S10 2TN, UK

Hong Jin[c]
School of Architecture
Harbin Institute of Technology
Harbin, P R China

ABSTRACT

Soundscape and sound preference are important in underground shopping streets, which are rather common in North-east China. These are typically long spaces, where the length is much greater than the width and height, and classic room acoustic theories are no longer valid. It is therefore of significance to examine the basic characterises of such sound fields. Intensive measurements were made in two long spaces in Harbin City, including an underground corridor in an office building, and an actual underground shopping street, considering both reverberation time and sound pressure level distribution. By comparing the two spaces, the effects of various special features in underground shopping streets were examined. Based on subjective surveys, relationships between the sound field characteristics and subjective soundscape evaluations in underground shopping streets are also briefly discussed.

1. INTRODUCTION

Underground shopping streets are rather common in North-east China, where winter is long and cold and people prefer indoor activities. Although common above-ground sound sources have little effect on those underground shopping streets, there are still many sound sources in them, some of which are preferred by users but many others could make people feel upset, stressful, exhausted and less concentrating. Soundscape and sound preference are therefore of significance in the design of underground shopping streets, for which it is important to examine the basic characterises of sound fields, since these spaces are typically long spaces, where the length is much greater than the width and height, so that classic room acoustic theories may not be applicable [1].

[a] Email address. tangzhengzheng8@yahoo.cn
[b] Email address. j.kang@sheffield.ac.uk
[c] Email address. jinhong_777yahoo.com

In this research, systematic measurements in two underground long spaces in Harbin City, China, were made in terms of the sound pressure level (SPL) and reverberation time (RT30), especially the variation along the length. By comparing the two spaces, the effects of various special features in underground shopping streets, such as the small store rooms along the street, and possible absorption and diffusion from the goods and furniture, were examined. In the mean time, a series of questionnaire surveys were made in two underground shopping streets, on the evaluation of soundscape and sound preference. In this paper these results are briefly presented.

2. METHODOLOGY OF ACOUSTIC MEASUREMENTS

Acoustic measurements were made in two underground long spaces in Harbin City, including a corridor in an office building, and an actual shopping street, Shi-Tou-Dao. The measurements were both made in night time when the background noise was low.

A. Underground Corridor

The plan and photos of the underground corridor are shown in Figure 1, where the source is marked as S and the receivers are marked as R. The width of the corridor was 3.1m and the height was 4.5m. With evenly distributed receivers along the corridor, the distance between R1 and R15 was 56.1m, and the distance between R16 and R40 was 102.5m. The distance between any receiver and the walls or other major reflecting boundaries was no less than 1m. An omni-directional sound source was used to play white noise. The receiver and source heights were both 1.2m. The SPL was measured using Norsonic121, as well as HS-3671 and BSWA801 sound level meters. The RT30 was measured using Norsonic121, and also by recording the signals using MP3 and then analysing them using 01dB software [2]. During the measurements the temperature was 25ºC and the relative humidity was about 66% [3].

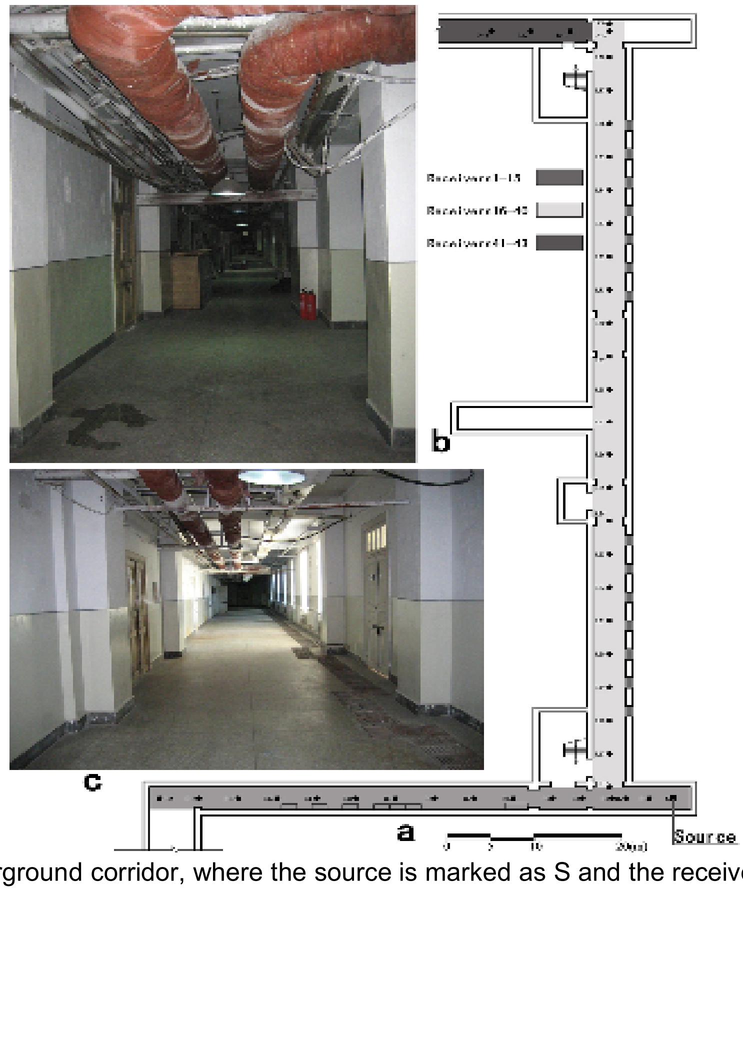


Figure 1: The underground corridor, where the source is marked as S and the receivers are marked as R.

B. Underground Shopping Street

The plan and photos of the underground shopping street are shown in Figure 2, where the total internal width including the stores was 15.3m, and the height was 5m. With evenly distributed receivers along the shopping street, the distance between R1 and R23 was 145.2m. The measurement equipment was the same as that in the underground corridor.

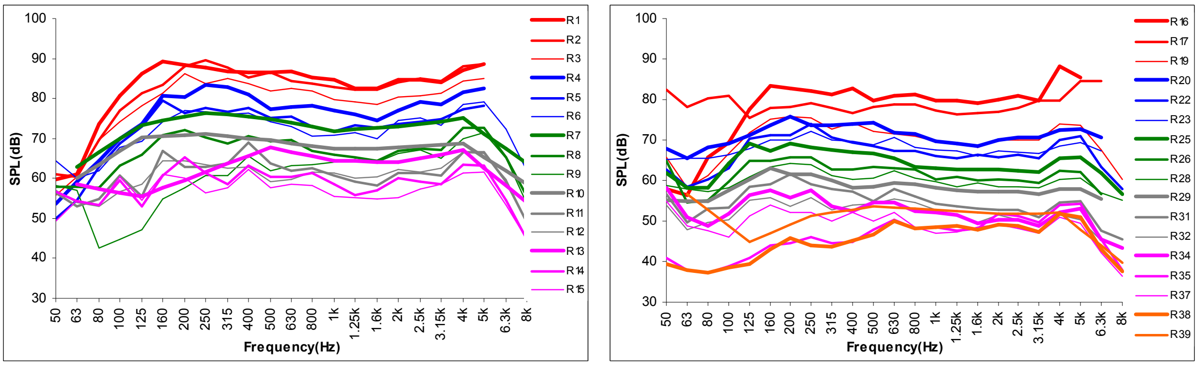
Figure 2: The underground shopping street, where the source is marked as S and the receivers as R.

3. SOUND FIELD

A. Underground corridor

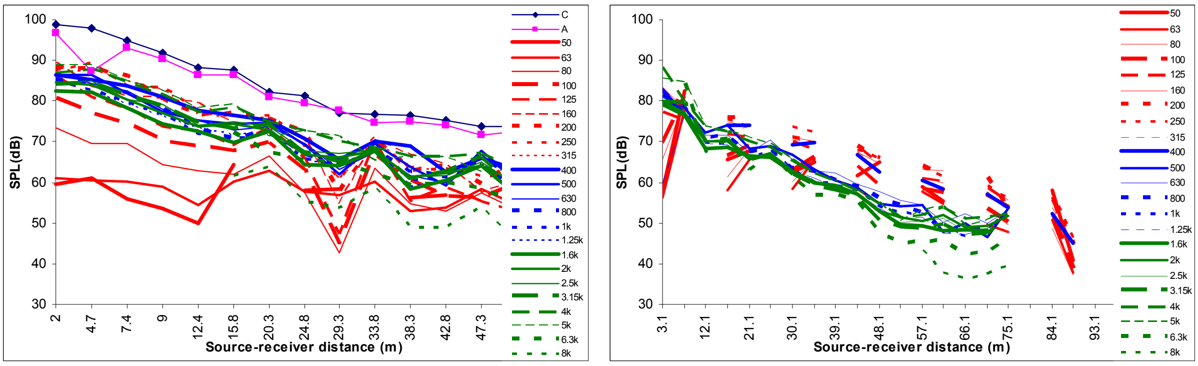
Figure 3 shows the spectra at various receivers in the corridor. Along R1-R15, as shown in Figure 3a, in the near field, due to the characteristics of the sound source, the SPL increases from 50 to about 200Hz, and then becomes stable. With increasing source-receiver distance, the spectra become relatively flat at various frequencies. In other words, the attenuation at high frequencies is considerably greater than that at low frequencies, as expected. Along R16-R39, as shown in Figure 3b, due to the 90^{o} change in sound propagation direction, the spectra are relatively flat at nearly all receivers except R16.

In Figure 4 the SPL attenuation along the length at various frequencies is shown. It can be seen that the SPL reduces continuously along the length at all frequencies, showing the feature of non-diffuse sound fields. At high frequencies the attenuation curves are relatively smooth and at low frequencies there is noticeable unevenness, due to room mode effects. This is more significant along R1-R15, compared with R16-39, due to the differences in source position. Also, compared with R1-R15, the SPL attenuation per unit distance is less along R16-R39.



(a) R1-R15 **(b)** R16-R39

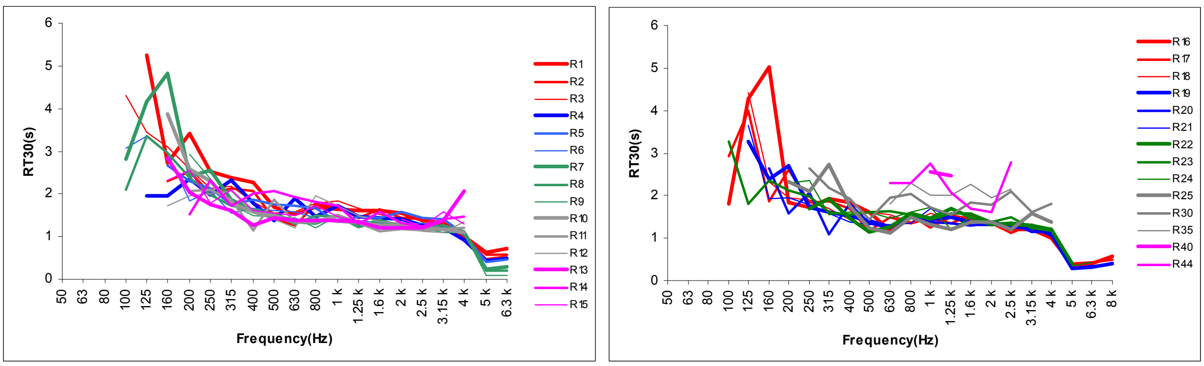
Figure 3: SPL variation with frequencies in the corridor.



(a) R1-R15 **(b)** R16-R39

Figure 4: SPL attenuation along the length in the corridor.

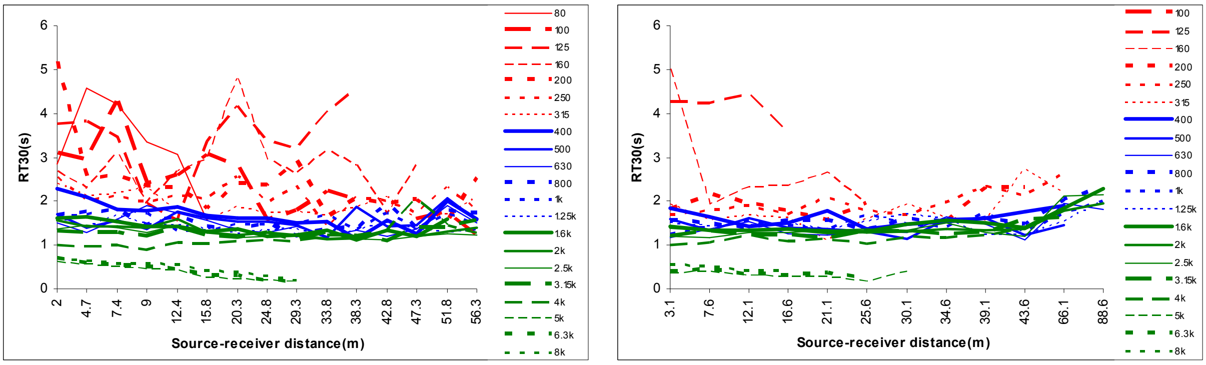
Compared to SPL, the variation in reverberation time is more significant. Figure 5 shows the RT30 variation with frequencies at various receivers in the corridor. It can be seen that with increasing frequency, the RT30 generally decreases, although along R16-39 this decrease is relatively less than that along R1-15. While the maximum RT30 could reach about 5s, generally the RT30 is around 1-2s.



(a) R1-R15 **(b)** R16-R39

Figure 5: RT30 variation with frequencies in the corridor.

In long spaces, the reverberation time along the length generally increases rapidly to a maximum and then decreases slowly with increasing source-receiver distance [1]. In Figure 6 is shown the RT30 variation along the length at various frequencies. It can be seen that while at low frequencies, as expected, there are considerable fluctuations, at middle and high frequencies the RT30 generally increases along the length, although the increase is not very significant, especially along R1-15. This is perhaps due to the strong boundary reflections.

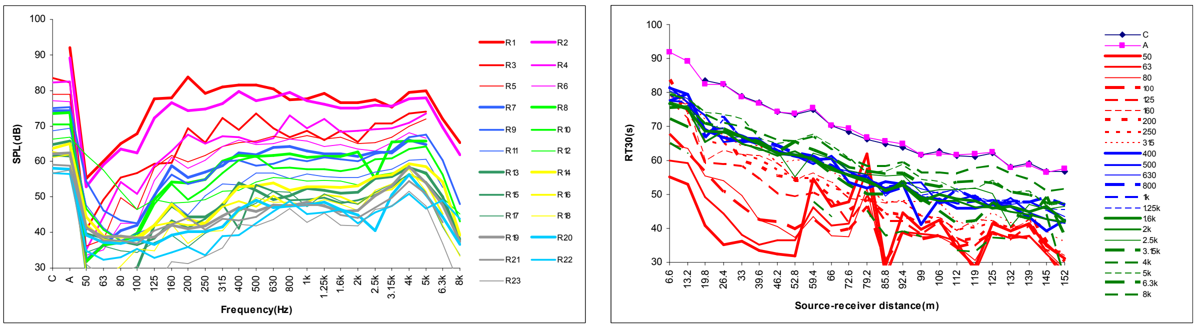


(a) R1-R15 **(b)** R16-R39

Figure 6: RT30 variation along the length in the corridor.

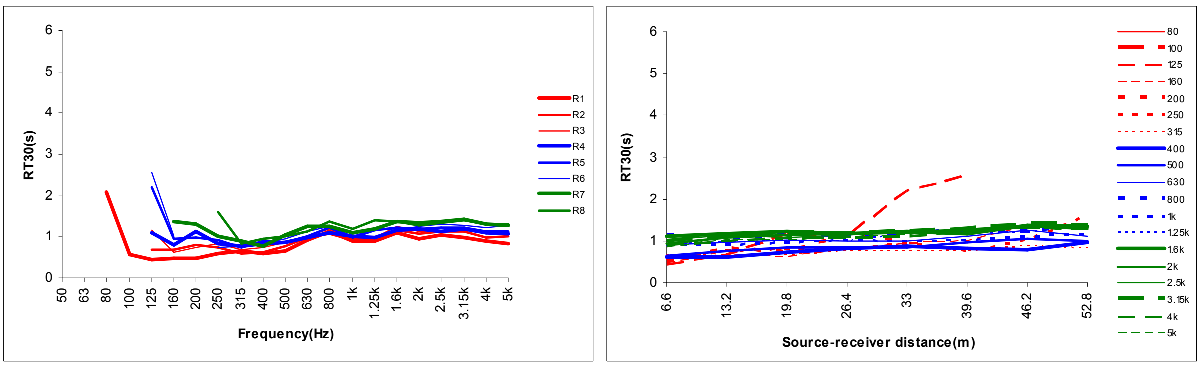
B. Underground Shopping Street

Figure 7 shows the spectra at various receivers in the underground shopping street. Similar to the corridor, the SPL increases from 50 to about 200Hz, and then becomes stable (see Figure 7a). The SPL reduces continuously along the length at all frequencies, at approximately 20-30dB at 100m, and at low frequencies there is noticeable unevenness (see Figure 7b).



(a) Variation with frequency **(b)** Variation along the length

Figure 7: SPL distribution in the underground shopping street.



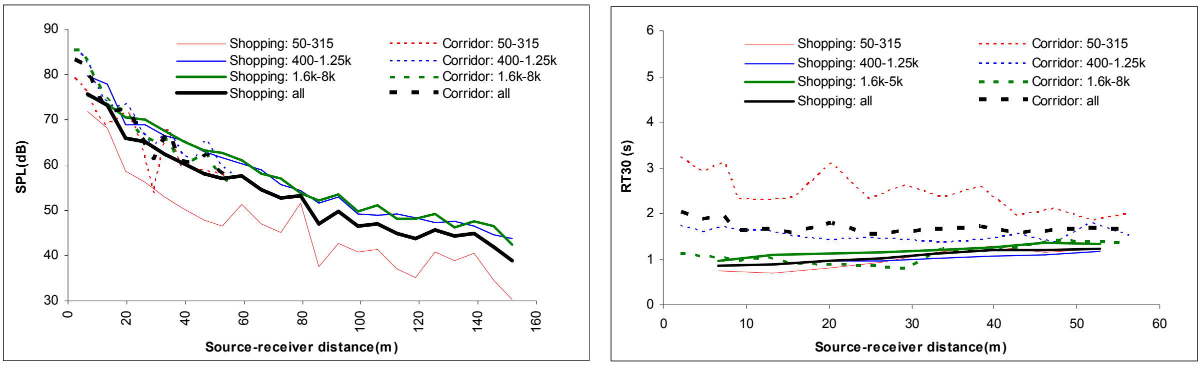
(a) Variation with frequency **(b)** Variation along the length

Figure 8: RT30 distribution in the underground shopping street.

Figure 8 shows the RT30 distribution at various frequencies at various receivers. It can be seen that RT30 increases along the length, and the variation between different frequencies are generally insignificant. RT30 is mostly around 1-1.3s.

C. Comparison between Two Spaces

Compared to the underground corridor, there are many special features in underground shopping streets, such as the small store rooms along the street, and possible absorption and diffusion from the goods and furniture. By comparing the SPL and RT30 in the above two spaces, as shown in Figure 9, the effects of those features can be examined. In Figure 9 it can be seen that in terms of the SPL attenuation along the length, there is no significant difference between the two spaces, whereas the differences in RT30 are considerable. In the corridor the RT30 is systematically longer than that in the shopping street, by about 60% on average across frequencies, and the difference is greater at lower frequencies. At 50-315Hz, 400-1.25kHz and 1.6k-8kHz, the difference is 147%, 54% and -6%, respectively. This is possibly caused by the low frequency absorption of small store rooms with goods and furniture, and also by more diffused boundary conditions in the shopping street. Moreover, in the shopping street there is a clearer increase in RT30 along the length. Overall, despite the differences between the two spaces, they are both of the long space characteristics [1], so that long space theories, rather than classic room acoustic theories, should be applied as design tools.



(a) SPL **(b)** RT30

Figure 9: Comparison in SPL and RT30 along the length between the underground corridor and shopping street.

4. SOUNDSCAPE AND SOUND PREFERENCE

With the understanding of basic acoustic characteristics in typical underground shopping streets, as discussed above, it would be useful to examine the evaluation of soundscape and sound preference in such spaces. An intensive questionnaire survey was carried out in two typical underground shopping streets in Harbin City, including Jin-Jie shopping street and Hong-Bo shopping street, with similar features as those in Shi-Tou-Dao, as discussed above.

A. Methods of Subjective Survey

A questionnaire was developed to assess the general soundscape, the range of recognised sounds and sound preference, as well as the awareness of different physical factors, which are useful for an integrative consideration of various factors and can also avoid any possibility of bias towards acoustic aspect. The questionnaire survey included three steps. The first step was to examine how many sound sources existed in the underground shopping streets and what kinds of words people would use to describe the sounds they heard. Ten interviewers asked randomly selected customers and owners. The second step was a detailed soundscape evaluation with a total sample size of 269 from customers and owners in the two sites. The third step was to carry out a survey with children and their parents in order to examine the possible correlations between them in terms of soundscape evaluation. Measurements of sound level were also conducted along with the questionnaire survey.

The results were analysed using SPSS. The basic profiles of the interviewees were first examined. There were more females (62%) than males (38%). While the age range was rather wide, around 38% of the interviewees were young people aged 18-24.

B. Initial Results

Table 1 shows the evaluation of general acoustic environment in the two underground shopping streets, based on the results at step 1, with 139 valid questionnaires. It can be seen that in both sites about 60% of the interviewees voted ‘noisy’ or ‘very noisy’, although there were many differences in terms of space form and sound sources between the two sites (see Figure 10). This means that in such spaces noise control is still an important issue, for which it is essential to consider the special acoustic features of long spaces.

In Table 1 the evaluation of echoing is also shown. It can be seen that less than 20% of the interviewees selected ‘strong’ or ‘very strong’, suggesting that generally speaking, such spaces are not reverberant and the control of reverberation may not be the top priority in designing the soundscapes.

Table 1: Evaluation of the acoustic environment and echoing in the two underground shopping streets.

	Acoustic environment			Echoing	
Scale	Jin-Jie	Hong-Bo	Scale	Jin-Jie	Hong-Bo
-2: Very quiet	0.0	0.0	-2: Very strong	4.5	2.8
-1: Quiet	7.6	11.1	-1: Strong	13.6	13.9
0: Neither quiet nor noisy	33.3	30.1	0: Neither strong nor weak	34.8	30.6
1: Noisy	47.0	51.4	1: Weak	31.8	38.9
2: Very noisy	12.1	6.9	2: Very weak	15.2	13.9

Figure 10 shows the first noticed sounds by interviewees. It can be seen that there are considerable differences between the two sites. For example, in Jin-Jie, the most noticeable sound was ‘speech from PA systems’ (31.4%), whereas in Hong-Bo the most noticeable sound was ‘speech between customers’ (46.9%). The differences could be caused by the variations in sound sources and/or in the profiles of interviewees who could pay more attention to different sounds, but could also be caused by the effects of sound fields on the propagation of different sources. It is therefore important to design the sound fields, in terms of sound attenuation along the length, considering the spectrum change due to boundary absorption and diffusion at different frequencies. In other words, improvements in soundscape could be made by better balancing different sound sources in terms of their levels and spectra.

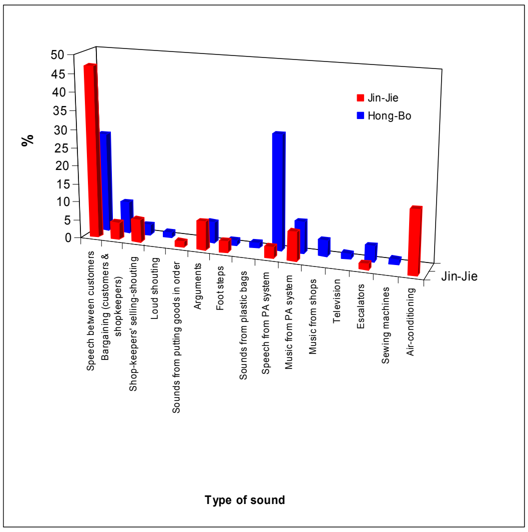


Figure 10: Most noticeable sounds in the two underground shopping streets.

5. CONCLUSIONS

In this study, basic characteristics of sound field in underground shopping streets have been examined, through a series of measurements of SPL distribution and reverberation, and also by comparing the sound fields between a typical underground shopping street and an underground corridor in an office building, which are both long spaces but with different functions and boundary conditions. It has been found that in the underground shopping street the SPL attenuates at approximately 20-30dB at 100m, and RT30 is mostly around 1-1.3s. Compared to the underground corridor, in the underground shopping street the SPL attenuation along the length is similar but the reverberation time, especially at low frequencies, is much shorter. Overall, it is clear that underground shopping streets are typical long spaces and in their soundscape design classic room acoustic theories should not be used.

The initial analysis of the subjective evaluation results shows that in underground shopping streets, noise control is important because most people think the spaces are noisy. In the mean time, given the complex situations in sound sources, it is of significance to consider the effects of the space form and boundary conditions on the level and spectrum balance of various sources, so that good soundscapes could be designed.

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