Evaluation of Acoustic Environment of High-Rise Residential Space

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Abstract. As the most common type of urban residential form, high-rise residential space is the main place for people's leisure and entertainment, so its acoustic environment quality is very important. In this paper, the acoustic environment of typical high-rise residential space is measured and analyzed, and survey questionnaires are statistically analyzed to explore the influence of listener's behavioural factors and social factors on the perception of soundscape. In order to provide reference for related design and management work. The results show that behavior factor such as activity frequency, time, location and social factors such as sex and age was associated with soundscape evaluation significantly.

1. Introduction
Architectural design is not only the creation of space forms, but also the shaping of the overall environment. At present, most studies about residential space’s acoustic environment only focus on the impact of traffic noise [1, 2]. However, traffic noise is not the only sound source that can disturb people. Especially in high-rise residential space, the population can be doubled, corresponding the sound types and their effects will be more complex. Previous studies have shown a lack of attention to the effects of living sound sources. In additions, some studies have shown that people's perception of sound is affected by factors such as the type of sound source, volume, and listeners’s individual differences, but not only sound pressure level (SPL) [3, 4]. Therefore, based on the analysis of sound field in high-rise residential space, this paper focuses on the sound source, to explore what sound sources that can really affect residents, how do people evaluate these sound sources, and what factors influence the subjective evaluation.

2. Methods
2.1. Site selection
This paper chooses the European new town community in Harbin as the investigation object, mainly based on three reasons. First, Harbin is a typical city in cold region in China, the provincial capital with the highest latitude and lowest temperature. In cold regions, the climate is cold in winter and lasts for a long time. In order to resist the attack of cold wind, the residential buildings are mostly enclosed and centralized. The enclosed building form of this residential space can representative cold region. Secondly, the residential occupancy is high and the age distribution of residents is balance, which is convenient for sampling survey. Thirdly, there are abundant sound sources in the community, and
each active spaces have different functions, covering different sound sources, so the sound field features are significant. Therefore, this residential space is selected as the research object.

2.2. Questionnaire survey
In order to get an objective and effective evaluation, residents were randomly selected for the questionnaire survey. Because of the small number of outdoor activities in Harbin in winter, the research was conducted in summer. The questionnaire questions are divided into two parts: one part is the background information of each respondents: Including social factors such as gender, age, work, residence time and floor height, as well as behavioral factors such as frequency of activities, activity items, duration, site. The second part is acoustic environment evaluation: Includeing an assessment of the sound source's volume and preference, and then SPSS was used for data entry and correlation analysis.

Among the 220 valid questionnaires collected, the ratio of male to female was 4.5:5.5. In terms of age distribution, there are more elderly over 60 years old, accounting for 24.9%. Retirement accounted for the highest number in working condition, accounting for 36.1%. Most of the residents lived for less than 3 years, accounting for 34.4%. Most of the outdoor visitors are living in the upper floors, 20.9% of them live above the 15th floor, 18% of the 10-14 floors, this basically according with the rule that the higher the residential floor, the more inclined the residents are to outdoor activities. In the activity item, playing with children topped the list at 26.5 percent.

2.3. Measurement method
At the same time of questionire, BSWA801 sound level meter was used to record the sound pressure level(SPL). The tests were conducted on weekdays. The sound level meter placed horizontally during measurement, the probe was 1.2m away from the ground, 1m away from the external wall, and 3.5m away from the reflector. The data were recorded once every 10s and tested continuously for 5 minutes at each point for a total of 30 times. The arrangement of measurement points is shown in the figure 1.

3. Characteristics and evaluation of acoustic environment

3.1. Characteristics of the acoustic environment
The distribution of sound is closely related to the spatial function. Each space has different functions and activity, contains different sound sources, and also presents different sound pressure level(SPL) in different times. According to the description of sound sources given by the interviewees in the survey, the sound sources can be roughly divided into natural sound, animal sound, artificial sound, musical sound, mechanical sound and traffic sound.

At 13:30 pm, it is the rush hour, traffic sound is the main sound source. As shown in figure 2, the SPL
of road space (P1 and P2) was up to 68.9 dB, which was significantly higher than that of other measuring points. At this time, the number of people in the courtyard (P3 and P4) was relatively small, acoustic environment was mainly influenced by the sound of traffic. Due to the shielding of buildings, the SPL in this courtyard was 10.7 dB lower than road. Because the residential’s internal road (P5, P8, P12) have no shelter to the direct traffic sound, so its SPL is 5.3 dB higher than adjacent yard. During the working time of 15:30 pm, SPL at all points changed significantly. They were all higher than noon, and the sound of propaganda trumpets and weeding machines were the main noise. There was a publicity campaign at P5, therefore the SPL increased to 11.9 dB due to the trumpets sound, reaching the highest SPL of 75.4 dB in the whole day. At P10 and P11, there were a weeding machines working, so the SPL increased by 21.8 dB. Except for P5, the SPL of other points which outside the yard was lower than courtyard, which indicated that the influence of living noise in this period was serious.

![Figure 2. Sound pressure level (SPL) of each measurement point.](image)

At 17:30 pm, it is the rush hour, traffic noise is the main source, and the peak of SPL is still at the P1 and P2, reaching the peak traffic noise (74.3 dB) of a day. During this period, crowds began to gather in the east square (P9), and the main sound sources were chatting sound, children’s frolicking sound and musical instrument sound. The SPL was increased by 6.7 dB. At 19:30 pm, it is the leisure time for residents after dinner. The number of residents in courtyard reached the highest in a day, and life noise was the main sound source. The peak of SPL at P6 (72.6 dB), which was higher than the traffic noise by 2-3 dB. There has public fitness facilities in this yard, so the main sound sources are children’s frolicking, chatting, dogs barking and musical instruments. At the P9 (71.2 dB) has square dance activity, so the music and square dancing sound were very noisy. Furthermore, P10 and P11 were in the innermost courtyard, with no sports equipment and the highest greening rate. The main sound sources were birdcalls, leaves rustle sound, and the courtyard had the lowest SPL (51.6 dB).

3.2. Evaluation of sound sources
In terms of sound source preference evaluation, the questionnaire results (figure 3) showed that residents’ favorite sounds were leaves rustle sound 63%, birdcalls 71.6%, and music 42.1%. In the artificial voice, although chatting’s volume is moderate, but it’s evaluation uncomfortable. In contrast, although the sound of children’s frolicking and square dancing was louder, but good
evaluation. There have 47.6% and 34.2% of the residents like children’s frolicking sound and square dancing sound, while only 14.5% are bored. This is not consistent with previous conclusions and expected low rating [5]. Combined with the survey results of residents' activities, it can be found that there are most elderly respondents in this community, and their main activities are playing with children and dancing in the square. Therefore, they are more receptive to such sounds. By contrast, chatting is hard to engage in, people always get annoyed with such sounds that have nothing to do with them.

The most annoying sounds for residents are mechanical sound such as propaganda trumpets 87.1%, construction noise 82.4%, weeding machines’ sound 69.3% and electric cars’ sound 49.4%. As well as traffic noise such as cars horn 73% and traffic passing sound 72%. Combined with objective data measurement, it can be seen that these sound always have high SPL and strong interference to surrounding residents.

Figure 3. Acoustic preference evaluation.

4. Influencing factors of acoustic environmental assessment

4.1. Behavioral factors

4.1.1. Frequency and time. The relationship between residents’ behavioral factors and acoustic environment evaluation is shown in the table 1. It was found that the visit frequency of residents was significantly correlated with the evaluation of traffic sound at p≤0.01. Indicates that the more often the residents activities in the yard, the greater the tolerance to traffic noise. Residents’ duration time is significantly correlated with children's frolicking sound, and comfort evaluation of acoustic environment and green environment. It indicates that the longer people stay in the residential space, the more acceptable to the noise of children, and the evaluation of acoustic environment and green environment is better, which is consistent with the previous research conclusions [6].

Table 1. The relationship between behavioral factors and soundscape evaluation.

| Sound source                  | Activity frequency | Activity project | duration time | site    |
|------------------------------|--------------------|------------------|---------------|---------|
| Dog bark                     | 0.054              | 0.051            | 0.149         | -0.361**|
| Chat                         | 0.015              | 0.024            | -0.013        | -0.243**|
4.1.2. Activity site. The activity site of the listeners was significantly positively correlated with the traffic noise and the acoustic environment at \( p \leq 0.01 \) and \( p \leq 0.05 \). This indicates that the closer the site is to the street, the lower evaluation of traffic noise, and also the lower evaluation of acoustic environment. On the contrary, activity site was significantly negatively correlated with dog barking, chatting, musical instruments, construction and electric cars. While these sound sources were all living noise, indicating that the farther away from the road, the lower the evaluation of living noise. This results are consistent with objective test’s data.

4.2. Social factors

4.2.1. Gender factors. The respondents’ gender only affected some sound sources (table 2). Gender was positively correlated with birdcall at \( p \leq 0.05 \), and negatively correlated with dog barking and construction sound. Combined with the acoustic preference evaluation (figure 3), it can be seen that the acoustic preference value of birdcall is higher, while dog barking and construction sound is lower. Presumably in high-rise residential space, compared with men, women feel more strongly to sound like or dislike.

4.2.2. Age factor. Previous studies on urban soundscape have found that age is correlated with acoustic comfort [7, 8]. However, in this study, age was only correlated with dog barking evaluation at the level of \( p \leq 0.01 \). This suggests that older listeners in higher residential areas are more sensitive to animal sounds, such as the dog barking sound.

| Sound source         | Gender  | Age     | Job     | Residence time | Floor height |
|----------------------|---------|---------|---------|----------------|--------------|
| Birdcalls            | 0.196*  | -0.127  | 0.166   | 0.161          | 0.161        |
| Dog Bark             | -0.218* | -0.281**| 0.059   | 0.069          | 0.069        |
| Construction noise   | -0.388**| -0.032  | 0.186   | 0.211          | 0.211        |

Note: * and ** indicate the significance level, * means \( p \leq 0.05 \), and ** means \( p \leq 0.01 \)

5. Conclusions

Based on the study of sound field and acoustic environment evaluation in high-rise residential space, the following conclusions can be drawn:

1. In the high-rise residential space, people have the highest evaluation on the natural sound. Different from previous research conclusions, the loudness and preference of children's frolicking sound and square dancing sound are both higher.

2. Behavioral factors influence acoustic environment assessment. The higher the frequency of visits, the stronger the listener's tolerance to the traffic noise. The longer residents stay in the residential space, the higher the evaluation of children's frolicking sound, acoustic environment and green environment.

3. Social factors influence acoustic environment assessment. Compared to men, women feel more...
strongly to sound. Different from previous studies, age only related to animal’s evaluation, the older the listener is, the more sensitive he or she is to animal sounds such as the dog barking. In this study, it was found that in addition to the influence of sound pressure level and listener’s personal differences, the acoustic environment of high-rise residential space was also affected by architectural layout. I will make further discussion in the next research.

6. Reference
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