Analysis of the impact of the urban traffic noise on the vertical distribution of high-rise residential buildings

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Abstract. With the rapid growth of China's urban population, the construction of its urban transportation network will be more vigorous than ever. The influence of road traffic noise on urban residential areas has become increasingly prominent. However, most of the current research is limited to the analysis of the flat sound field, leaving the research on high-rise residential vertical sound not so detailed. This study aims to find out the vertical sound field distribution law of traffic noise to high-rise buildings on the sides of the road. We monitored the environmental traffic noise effects in a high-rise residential area in Zhejiang Province and established a high-rise residential model in the SoundPLAN Software to simulate the vertical sound field distribution of traffic noise. The law is that the value rises sharply to the peak in the range of 0-7F (23.0m) then decreases slowly as the height increases. We also made a linear analysis of the noise data to arrive at a linear regression equation. This study provides a new way of taking noise prevention and control into consideration in high-rise housing. Special attention must be given to the isolation of traffic noise on floors by selecting soundproof doors and well-functioning windows. This strategy of creating a high-quality sound environment in a residential area can be put forward to improve people's lifestyle and environment.

1. Introduction
With China's urbanization entering a high-speed development stage, expansion occurs not only in terms of the scale of the city but also in terms of population. Moreover, the number of various motor vehicles has increased dramatically, causing great pollution to the urban environment[1]. According to the China Environmental Noise Prevention and Control Annual Report (2020), China's 12,396 Environmental Reporting Network Management Platform received 531,176 reports in 2019. Among these, there were 202,378 cases of noise interference, accounting for 38.1%, ranking second in the pollution factor. Traffic noise complaints were 8,258, representing 4.1% of the total number of complaints.

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2. Related works of traffic noise on urban roads
In recent times, there have been studies on the effects of traffic noise on urban roads. Lu Xiaodong et al [2] put forward a preliminary study of the influence factors of high-level traffic noise based on road visibility. Yang Lin et al. [3] analyzed road areas with the greatest impact on the noise of high-rise buildings. Ma Jianhua et al. [4] put forward a vertical distribution simulation of environmental noise in high-rise buildings based on Cadna/A. Sun Tao [5] studied the influence of urban traffic noise on high-rise buildings and the optimal design strategy of sound barriers against noise transmission. Yang Yajie [6] assessed the environment and noise control of residential areas along the high-speed railway.

3. Methodology

3.1 SoundPLAN Software
SoundPLAN Software was developed in 1986 by the software designers and consulting experts of Braunstein und Berndt GmbH. Since its release, SoundPLAN has rapidly become the standard of German outdoor acoustic software and has gradually become the world's leading software for noise prediction, mapping, and evaluation [7].

3.2 Noise control standards
The standard based on the quality test and evaluation of the sound environment in urban functional areas is the Sound Environment Quality Standard (GB 3096-2008) (Table 1). The evaluation index is the compliance rate of day and night monitoring points. The environmental noise limits for various acoustic environment ribbons can likewise be found in Table 1. Because we’ll study the limits of noise's effect on residential buildings, we should choose Category 1.

| Functional zone | Type 0 | Type 1 | Type 2 | Type 3 | Type 4a | Type 4b |
|-----------------|--------|--------|--------|--------|--------|--------|
| daytime         | ≤50    | ≤55    | ≤60    | ≤65    | ≤70    | ≤70    |
| nighttime       | ≤40    | ≤45    | ≤50    | ≤55    | ≤55    | ≤60    |

4. Experiment & Results

4.1 Overview of the pilot project
The experiment takes a residential area in Zhejiang Province, China as an example. The district covers an area of 138,000 m², with a total construction area of 320,000 m², and the total number of households is 1986. Community buildings include residential buildings, commercial complexes, kindergartens, recreation clubhouses, and sustainable public green spaces. The residential block faces four roads, with a secondary express road on the north side and eight lanes on both directions. The road width is 60 meters. The road traffic noise on the north side interferes with the lives of residents and is often complained about. Hence, we decided to determine the traffic noise value of the north side highway and to analyze the distribution of vertical façade noise in the software.

4.2 Data records
Traffic noise data collection uses a Tinfor-071/2 continuous noise monitor. This instrument is capable of continuous inspection for 24 hours. It not only has a GPS positioning function but also enables simultaneous monitoring.
4.3. Experimental analysis
After importing the data into the sound planning software and setting the parameters, we came to some conclusions. Road traffic noise on the north side of high-rise residences is loud and exceeds the noise limit. On high-rise residential buildings along the street, the noise value is about 66-72dB. About 90% of high-rise residential floors are exposed to noise from 60-66dB. The noise value on the top 2-3 layers of the house and the east and west side walls is approximately 57-60dB (Table 2).

Table 2. Noise values for all test locations

| Descriptive Statistics | N   | Minimum | Maximum | Mean  | Std. Deviation |
|------------------------|-----|---------|---------|-------|---------------|
| dB (A)                 | 504 | 39.1    | 63.0    | 53.807| 8.1505        |
| height                 | 504 | 4.5     | 95.8    | 48.946| 25.7381       |

We set up four points on the north side of the high-rise residence, numbered 116, 117, 118, and 119 (Figure 1). Each point collects four noise values at the height of each floor, comprising four directions: East, West, South, and North. In the end, we obtained 504 data samples. First, we analyzed all the data samples and found that the minimum noise value is 39.1dB, the maximum noise value is 63dB, and the average noise value is 58.807dB. This test should be classified as a category 1 area for analysis. From the Sound Environment Quality Standard, it can be seen that the environmental noise limit of type 1 area is 55dB. The average noise value of the monitoring area exceeds 6.9% of the limit.

4.4 Dumb variable processing
Because each test point contains four noise values in different directions. However, if we study the distribution of traffic noise to vertical noise in high-rise residential buildings, the north side of the building adjacent to the road should be focused on. Hence, we build a database in SPSS, which contains the classification variable direction. We define it as a dumb variable to see how each direction affects the noise value.

Table 3. Dumb variable processing

| Coefficientsa | Model   | Unstandardized Coefficients | Standardized Coefficients |
|---------------|---------|-----------------------------|----------------------------|
|               |         | B  | Std. Error | Beta | t  | Sig. |
| 1 (Constant)  |         | 61.332 | .132 |       |     |     |
| East          | -3.442  | .187 | -.196     | -18.393 | .000 |
| West          | -3.474  | .187 | -.198     | -18.560 | .000 |
| South         | -19.311 | .187 | -1.098    | -103.184 | .000 |
| North         | 0       |     |           |       |     |

a. Dependent Variable: dB (A)
From the table above (Table 3), we can draw the following conclusions:

1. Compliance on the east side is significantly lower than on the north side by 3.442 ($p < 0.005$).
2. Compliance on the west side is significantly lower than on the north side by 3.474 ($p < 0.005$).
3. Compliance on the south side is significantly lower than on the north side by 19.311 ($p < 0.005$). So we abandoned the noise values in the other three directions and simply linearly fitted the north noise data with the vertical sound field.

According to the law of noise and sound wave propagation, the noise data on the opposite side has the most research value. Because the noise of the sidewall and the backside will produce diffraction attenuation and sound reflection phenomenon.

4.5 Preliminary linear regression fitting analysis

Let's look at the noise data for each point. For 119 points (Figure 2 and Table 4), the noise data between 0-14.6m rose sharply from 41.5dB to 62.6dB, and the noise above 14.6m slowly decayed to 59.7dB. For 118 points (Figure 3 and Table 5), the noise data between 0-14.6m rose sharply from 41.9dB to 63dB, but the noise over 14.6m was reduced to 59.5dB. For 117 points (Figure 4 and Table 6), the noise data between 0-14.6m rose sharply from 41.9dB to 63dB, and maintain the peak in the height range of 14.6-20.2m. However, the noise over 20.2m was reduced to 59.5dB. For 116 points (Figure 5 and Table 7), the noise data between 0-14.6m rose sharply from 41.8dB to 63dB and maintained the peak in the height range of 14.6-17.4m. However, the noise above 17.4m decayed to 59.8dB.

Taken together, the noise value of high-rise residential facades increases dramatically as the floor rises then slowly declines. The noise peak is about 7F (23.0m) high, so we take all the north side data of 7F and above to do the linear regression fit analysis.

### Table 4. The coefficients of noise values on the north side of 119 points

| Model | Unstandardized Coefficients | Standardized Coefficients | t | Sig. |
|-------|-----------------------------|---------------------------|---|------|
|       | B   | Std. Error | Beta |       |     |
| 1     | (Constant) | 55.464 | 2.108 | 26.314 | .000 |
|       | height | .087 | .040 | .382 | 2.187 | .037 |

*a. Dependent Variable: dB*

Fig. 2. The scatter plot of noise values on the north side of 119 points.
Table 5. The coefficients of noise values on the north side of 118 points.

| Model | Unstandardized Coefficients | Standardized Coefficients | t     | Sig. |
|-------|-----------------------------|---------------------------|-------|------|
|       | B          | Std. Error | Beta  |       |      |
| 1     | (Constant) | 56.662     | 1.930 | 29.366 | .000 |
| height | .063       | .034       | .320  | 1.883 | .069 |

a. Dependent Variable: dB

Fig. 3. The scatter plot of noise values on the north side of 118 points.

Fig. 4. The scatter plot of noise values on the north side of 117 points.
Table 6. The coefficients of noise values on the north side of 117 points.

| Coefficientsa | Unstandardized Coefficients | Standardized Coefficients | t | Sig. |
|---------------|-----------------------------|---------------------------|---|------|
| Model         | B                           | Std. Error                | Beta | t    | Sig. |
| 1 (Constant)  | 56.677                      | 1.931                     | 29.345 | .000 |
| height        | .063                        | .034                      | .319   | 1.876 | .070 |

a. Dependent Variable: dB

Fig.5. The scatter plot of noise values on the north side of 116 points

Table 7. The coefficients of noise values on the north side of 116 points.

| Coefficientsa | Unstandardized Coefficients | Standardized Coefficients | t | Sig. |
|---------------|-----------------------------|---------------------------|---|------|
| Model         | B                           | Std. Error                | Beta | t    | Sig. |
| 1 (Constant)  | 55.773                      | 2.131                     | 26.178 | .000 |
| height        | .086                        | .040                      | .371   | 2.117 | .043 |

a. Dependent Variable: dB

4.6 Linear fit of all noise data above 7F

Through the SPSS neutral regression analysis (Table 8), we get R square fitting degree of 97.8%, indicating a high fit. This indicates that the vertical sound field distribution of road traffic noise is 97.8% dependent on the change in height. It is significant at $p < 0.05$, indicating that height is an important factor, which can greatly affect the vertical sound field distribution of noise. We came up with the following linear regression equation (Table 9):

Noise value (dBA) = 64.043 - 0.047 × height.
Table 8. Regression analysis

| Model | R     | R Square | Adjusted R Square | Std. Error of the Estimate | R Square Change | F    | df1 | df2 | Sig. F Change |
|-------|-------|----------|-------------------|---------------------------|----------------|------|-----|-----|---------------|
| 1     | .989a | .978     | .978              | .1475                     | .978           | 4522.905 | 1   | 100 | .000          |

a. Predictors: (Constant), height

Table 9. Coefficients

| Coefficientsa | B      | Std. Error | Beta  |
|---------------|--------|------------|-------|
| (Constant)    | 64.043 | .043       | 1494.039 | .000 |
| height        | -.047  | .001       | -.989  | -67.253 | .000 |

a. Dependent Variable: dB (A)

5. Discussion

All four points 116, 117, 118, and 119 saw a spike in noise at 7F (23.0m) altitude. Each point has four different directional noise values. To determine which direction is more dependent on the height variable, we defined direction as a dumb variable. We concluded that the north side noise data is more dependent on height variables. Finally, we fit the north side noise data to arrive at the linear regression equation.

Noise value (dB) = 64.043 - 0.047 × height.

The distribution law of noise field in the vertical direction of high-rise residential is expounded. It is not that the higher the height of the building, and the farther away from the road, the less noise the value. It provides a new way of taking noise control into account in high-rise housing. Therefore, noise prevention and control measures should be strengthened on floors between 7-8F (2.8 m per layer).

6. Conclusions

This study takes an actual high-rise residential building in Zhejiang Province as an example and collects the value of road traffic noise on the spot. After obtaining linear sound source data for road traffic, we performed software simulations of noise values on different floors. The pattern of noise distribution in the sound field of high-rise buildings is that the value rises sharply to the peak in the range of 0-7F (2.8 m per layer) then decreases slowly as the height increases.

Therefore, high-rise residential design should pay attention to the vertical surface of the noise impact. In particular, noise usually peaks at 7-8F (2.8 m per layer). We should pay more attention to the isolation of traffic noise on these floors by selecting soundproof doors and well-functioning windows since 90% of the external noise comes in from these openings. If the design uses hollow double-glazed windows and plastic steel flat sealed windows, you can isolate 70% to 80% of the traffic noise, while ordinary aluminum alloy single-layer glass windows can only isolate 30% to 40% noise.

By obtaining the law of vertical sound field distribution of traffic noise, we can put forward corresponding strategies to improve the traffic environment noise in the district. We hope that these strategies can somehow help people create a more comfortable and pleasant living environment.

While this research has significant value, it still has some problems that can be further studied by the researchers. For example, after the height of the residential building exceeds the 100m limit, the distribution law of noise data is not yet known. Further research can be made on the effect of the distance from residential to urban roads on noise propagation. Moreover, researchers can look into whether the flat combination of high-rise buildings will affect the spread of noise and so on.
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