



Environmental Noise Assessment of 18-Storey Residences in Dingqiao, China

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Abstract. Noise-level measurements of household appliances and road traffic from residential buildings in Dingqiao are conducted using a noise-level analyser and integrating sound metre. The environmental noise status of 18-storey residences is evaluated using sound pressure level (SPL) constraints with superimposed direct and reflected sounds. Octave-band operations reveal that the SPLs of the main appliances closely obey the following order: fluorescent lamp < air conditioner unit < computer < refrigerator < smoke exhaust ventilator. The SPL of the road traffic is found to range from 54.6 to 73.8 dB(A). Furthermore, neither the fluorescent lamp nor the computer exceeds the prescribed limit, whereas the smoke exhaust ventilator, air conditioner unit, refrigerator, and road traffic exhibit contrasting trends.

Keywords: 18-Storey Residences, Noise Assessment, Sound Pressure Level.

1 Introduction

Numerous noise sources, primarily indoor and outdoor environmental noise, affect high-rise residential buildings [1–3]. Indoor noise sources include household appliances and activities in residential areas [4], whereas outdoor noise is complex and mainly comprises traffic noise [5, 6]. Excessive noise can cause people to wake up earlier than expected and later experience fatigue. Long-term living in a noisy environment can result in hearing loss or even deafness, which affects people's moods and leads to impatience and irritability [7, 8]. Moreover, symptoms of neurasthenia, such as dizziness and tinnitus, may occur with noise exposure in urban dwellings [9].

Noise pollution in residential areas of Zhejiang Province is gradually becoming worrisome [10]. In recent years, among the complaint letters received regarding domestic pollution, noise pollution accounted for half of the total letters. Most residents complained about noise interference in high-rise residential buildings. Researchers have focused on investigating the distribution and acoustic characteristics of combined construction noise [11] to provide technical references for noise control and its effect on

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annoyance. Relevant investigations on household appliance noise [12–15] have revealed that the noise levels of washing machine, regular dishwasher, cooling fan, motor and home theatre in residential apartments are typically > 40 dB(A).

This study aimed to develop an improved method for determining noise levels. The environmental noise assessment of 18-storey residences was the main objective, and an analytic hierarchy process method was used to determine traffic noise and appliance noise by referring to the construct of a multi-level criteria system. In optimised configurations, the noise permeation was a characteristic index of appliance selection. Conclusions regarding the noise conditions of household appliances and traffic flow were drawn. Sound pressure level (SPL) measurements with superimposed direct and reflected sounds were calibrated, particularly at specific source points in habitable rooms of high-rise residential buildings.

2 Methods

2.1 Apparatus and Test Objective

A NTi Audio XL2 noise-level statistical analyser with accuracy index of 0.04 Hz (Switzerland), HS5731 octave filter (China), and Extech 407780-NIST integrating sound level metre (USA) were used.

The test objectives were a smoke exhaust ventilator, air conditioner unit, refrigerator, computer, fluorescent lamp, and road traffic in 18-storey residences in Dingqiao, China. The environmental noise of buildings was analysed according to these standards: BS-EN-61260 “Electroacoustics, octave-band, and fractional-octave-band filters,” GB 3096 “Environmental quality standards for noise,” and GB 50118 “Code for design of sound insulation of civil buildings.”

2.2 Noise-level Measurements

The test site was Dingqiao, which was located in the Shangcheng District of Hangzhou, Zhejiang Province. Numerous motor vehicles were parked at the periphery of the test site, and the traffic flow was monitored in the morning and evening rush hours. Noise levels of household appliances were measured at 22:00 to eliminate the influence of other noise on the experimental data. Other devices that might produce sounds were turned off and only the test devices were retained. The test point for household appliance noise was fixed (1 m from the appliance). Each datum with good repeatability was the average of three parallel groups. The background noise was low according to this test method. For traffic noise, the measurements were divided into three periods: early (8:00–9:00), middle (12:00–13:00), and late (18:00–19:00).

2.3 Noise Assessment Index

According to the GB 50118, sound can be estimated based on the applicability of the *A*-weighted SPL. In terms of nonindustrial and household appliance noise [16], the

noise assessment matrix for high-rise residential buildings was calculated using the following equation:

$$A = \begin{bmatrix} 1 & 6 & 7 & 4 & 5 & 2 & 3 \\ 1/6 & 1 & 2 & 1/3 & 1/2 & 1/6 & 1/4 \\ 1/7 & 1/2 & 1 & 1/4 & 1/3 & 1/7 & 1/5 \\ 1/4 & 3 & 4 & 1 & 2 & 1/4 & 1/2 \\ 1/5 & 2 & 3 & 1/2 & 1 & 1/5 & 1/3 \\ 1/2 & 6 & 7 & 4 & 5 & 1 & 3 \\ 1/3 & 4 & 5 & 2 & 3 & 1/3 & 1 \end{bmatrix} \quad (1)$$

The characteristic phasor obtained using the square root can be expressed by Equation (2):

$$P = \begin{bmatrix} P_1 \\ P_2 \\ P_3 \\ P_4 \\ P_5 \\ P_6 \\ P_7 \end{bmatrix} = \begin{bmatrix} 0.3415 \\ 0.0423 \\ 0.0292 \\ 0.0968 \\ 0.0639 \\ 0.2801 \\ 0.1462 \end{bmatrix} \quad (2)$$

The consistency test is assessed to eliminate subjective bias:

$$\lambda_{\max} = \sum_{i=1}^n \frac{(A \times P)_i}{nP_i} \quad (3)$$

$$C_R = \frac{\lambda_{\max} - n}{(n-1) \times 1.32} \quad (4)$$

where λ_{\max} is the maximum eigenvalue of the judgement matrix, and C_R is the consistency ratio ($n = 7$).

The λ_{\max} and C_R values were 7.2 and 0.025, respectively; herein, C_R was lower than 0.1, which indicates that the consistency test of the judgement matrix was feasible. The noise of 18-storey residences primarily originated from traffic and activity noise, accounting for a significant proportion of the weighting (household appliance noise > traffic noise).

3 Results and discussion

3.1 Noise Level of Household Appliances

In high-rise houses, the location of household appliances, size of the room structure, and sound absorption characteristics of the decorative materials amplify the noise via sound reflection. Hence, the noise emitted by household appliances is louder than the SPL evaluated in specific environments. As the acoustic propagations of household appliances at the time of delivery are different, SPL detection was required to reveal the relationship between the noise level and the residential area. However, the allowable noise level in the bedroom is ≤ 45 dB(A) during the day and ≤ 37 dB(A) at night, whereas that of the living room is ≤ 40 dB(A) throughout the day when the windows are closed.

In addition to the resonance caused by improper installation, household appliance noise originates from ventilation and air conditioning systems. The sound sources include pumps, fans, refrigerators, constant-speed machines, air ducts, and air inlets. The influence quantity consisted of the sound absorption coefficient and acoustical reduction factor. With an increase in the sound absorption coefficient and room area, the sound pressure decreased sharply. Considering that the simplification points of the household appliances were consistent, the SPL analysis at central frequencies of 30, 125, 250, 500, 1000, 2000, and 4000 Hz were compared. As listed in Tables 1–5, the reflected sound was independent of the distance from human ears to the source when the SPL heard at any location was relatively the same. The SPL of tall buildings preliminarily decreased at a frequency of ≥ 1000 Hz. The air conditioner unit and fluorescent lamp introduced a slight noise nuisance in daily life.

Table 1. Noise octave results for smoke exhaust ventilator.

Frequency	30	125	250	500	1000	2000	4000
	67.9	80.2	72.3	66.1	61.7	57.7	55.1
SPL	67.0	79.7	72.4	66.3	61.4	57.1	55.3
	67.1	79.3	72.6	66.4	61.6	57.5	55.0

Table 2. Noise octave results for air conditioner unit.

Frequency	30	125	250	500	1000	2000	4000
	58.8	61.2	54.7	59.0	51.9	51.6	57.4
SPL	58.9	61.0	55.1	58.7	52.3	51.5	57.2
	58.0	61.1	56.2	59.1	52.2	51.7	56.8

Table 3. Noise octave results for refrigerator.

Frequency	30	125	250	500	1000	2000	4000
	68.3	74.4	69.3	64.6	62.6	52.9	49.1
SPL	68.6	74.7	69.8	64.5	62.8	52.7	49.5
	69.0	74.5	69.5	64.8	63.0	52.6	49.4

Table 4. Noise octave results for computer.

Frequency	30	125	250	500	1000	2000	4000
	61.0	68.6	64.3	66.5	56.4	55.1	57.5
SPL	60.7	68.3	64.2	66.1	56.9	55.8	57.2
	60.5	68.5	64.6	66.2	56.7	55.2	57.9

Table 5. Noise octave results for fluorescent lamp.

Frequency	30	125	250	500	1000	2000	4000
SPL	43.1	37.9	40.2	41.3	43.6	36.8	43.3

43.2	37.8	40.0	41.1	43.5	36.4	43.2
42.7	37.5	40.4	40.6	43.8	37.2	43.4

Figures 1–5 indicate that the octave-band noise of household appliances is a critical index for evaluating the typical noise levels of high-rise residential buildings. Following the addition of 10 dB(A), the noise was truly heard. The SPL reached at least 36.4 dB(A) for 1-m distance from household appliances. *A*-weighted SPL was determined to describe the noise level of household appliances, and the attenuation speed was inversely proportional when the external sound exceeded the operating noise. The octave analysis revealed the ambient noise of the major appliances, and the SPL was found to obey the order: fluorescent lamp < air conditioner unit < computer < refrigerator < smoke exhaust ventilator.

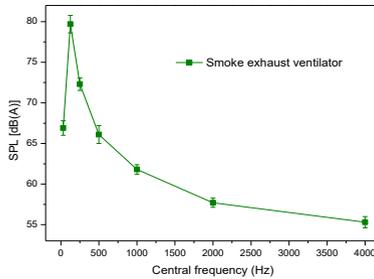


Fig. 1. Noise impact graph of smoke exhaust ventilator.

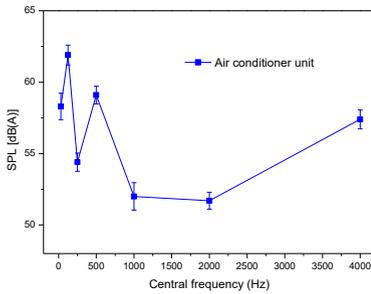


Fig. 2. Noise impact graph of air conditioner unit.

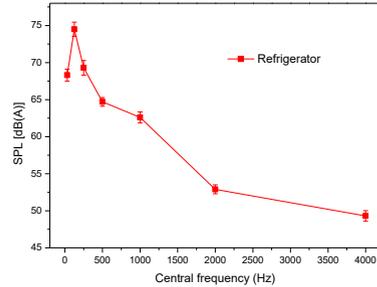


Fig. 3. Noise impact graph of refrigerator.

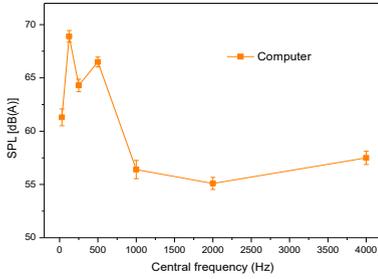


Fig. 4. Noise impact graph of computer.

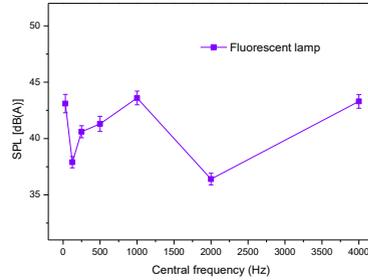


Fig. 5. Noise impact graph of fluorescent lamp.

3.2 Noise Level of Urban Road Traffic

Chinese mandatory standard GB 3096 was adopted for testing road traffic noise. The distance of monitoring point from the road was 5.5 m (1.4-m height above the ground). The allowable noise level of the road traffic ranged between 62 and 74 dB(A) [17]. Among the monitored roads which were measured outdoors, 54 % of the total length exceeded 70 dB(A). On both sides of the traffic trunk road, the percentage of the residential areas was *ca.* 58 %, and those for the cultural and educational areas were *ca.* 11 %. The remainder was in mixed commercial areas, and the noise levels during the morning and evening rush hours were considerable owing to the noise pollution of urban motor vehicles.

The acoustic environment of the 18-storey residence was measured by considering three periods of relevant traffic flow (Table 6). Subsequently, the mean values versus urban roads for potential traffic circulation were reported, and the SPL values followed the order: (12:00–13:00) < (8:00–9:00) < (18:00–19:00). Interestingly, the noise levels of engines and tyres ranged from 54.6 to 73.8 dB(A), and the equivalent frequency was easily induced by light-duty vehicles in traffic flow.

Table 7 presents the noise measurement results obtained for living scenarios of 18-storey residences. The *A*-weighted SPLs of the refrigerator, air conditioner unit, smoke exhaust ventilator, and road traffic exceeded 45 dB(A), and the residential noise related to the equivalent sound level impacted the annoyance of the sound receivers. The analysis confirmed that neither the fluorescent lamp nor the computer exceeded the prescribed limit. However, the smoke exhaust ventilator, air conditioner unit, refrigerator, and road traffic exceeded the limit to varying degrees. Acoustic damping materials, alternative sound absorption materials, and newly established green belts have been developed to minimise the thermal-noise effect of high-rise residential buildings.

Table 6. SPL values of road traffic noise.

Period	8:00–9:00	12:00–13:00	18:00–19:00
SPL	65.9	54.6	71.7

68.7	54.8	70.5
69.0	55.9	73.8

Table 7. Summary of noise data for 18-storey residences.

Factor	A-weighted SPL	Out of gauge
Smoke exhaust ventilator	70.2	Yes
Air conditioner unit	59.3	Yes
Refrigerator	65.8	Yes
Computer	45.0	No
Fluorescent lamp	41.1	No
Road traffic	67.6	Yes

4 Conclusion

The noise levels of household appliances and road traffic from 18-storey residences in Dingqiao were evaluated using an effective example-based method. Based on the analytic hierarchy process, the noise within residential buildings originated primarily from appliance noise and traffic noise. Octave-band operations at 30, 125, 250, 500, 1000, 2000, and 4000 Hz were compared. The *A*-weighted SPLs were ≥ 36.4 dB(A) for 1-m distance from household appliances, and those of the refrigerator, air conditioning unit, smoke exhaust ventilator and road traffic were ≥ 45 dB(A). The noise octave measurements indicated that the appliance SPL was in the order of the fluorescent lamp < air conditioning unit < computer < refrigerator < smoke exhaust ventilator. The SPL of road traffic was evaluated (5.5-m distance from the road and 1.4-m height above the ground), and found to be follow the order: (12:00–13:00) < (8:00–9:00) < (18:00–19:00). Environmental noise controls, such as acoustic damping materials, alternative sound absorption materials, and newly established green belts thereby extend the application of noise reduction techniques.

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