INVESTIGATION OF THE NOISE ATTENUATION FROM OUTDOOR TO INDOOR OF TYPICAL RESIDENTIAL BUILDINGS IN CHINA

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1. INTRODUCTION

Nowadays, more and more people in china began to suffer from the noise pollution due to the rapid urban development. During the transmission process, noise would produce the phenomena of reflection, refraction, diffraction and attenuation. Noise attenuation has relationship with many factors, such as distance radiation, air absorption, ground absorption, barrier and weather condition [1]. Utilizing these attenuation factors during the noise transmission process can efficiently improve the indoor acoustic environment.

Setting up sound barrier is a frequently used way to reduce noise, and there are many researches on various types of barriers' effect and applications in practical projects [4]. As to comparatively small quantity of noise attenuation, developing virescence is considered as the cheapest way.[1,2] In addition, there have been some researches on the noise attenuation effect of different enclosure structures, materials and forms of wall, as well as noise-defend door and noise-defend windows [5]. There are also researchers systematically analyzing factors that affect balcony's impact on noise attenuation [6].

However, these researches only aim at certain parts in buildings to compare the testing of noise attenuation, but haven't systematically considered various factors affecting this attenuation, and haven't analyzed the enclosure structures, doors and windows as a whole, also have not presented feasible calculation ways. Therefore, this paper analyzed various factors of noise attenuation such as enclosure structures, doors and windows as a whole, and research on the specific noise attenuation from outdoor to indoor of buildings, and explore whether there are differences of noise attenuation among different time.

2 METHODS

2.1 Subjects

A typical roadside residential building in Chongqing, China is selected and named Building A. Building A is 50 meters away from the main road and 11meters from the outdoor ground. The balcony of Building A is with closed board at three sides, and the top of balcony is open. The sitting room is next to the balcony. Other components of Building A is described as follows, glass sliding door, sing-glazed alum frame windows, concrete slab floor and concrete cinder-block plaster wall. This style of building is widely adopted in the south of China (see figure 1).

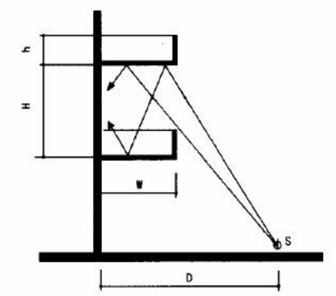

Figure 1: Sketch of balcony of Building A

2.2 Measurement equipments

Instruments used for the measurements are TES-1352A sound level meters (made in China). And its parameter is as follows: available to link with computers; directly record 16000 original noise data; added with functions of clock and calendar; precise tolerance: ±1dB; frequency response: 31.5 Hz~8 KHz. When the sound level meters are connected with computers, time can be automatically renewed in order to collate precise time. And the sampling time is fixed one second.

2.3 Testing methodology

Before measurement, two high-precision sound level meters are collated with identical time to one second. Measurement in balcony and sitting room is carried out at the same time, and the data is recorded automatically every second. The sound meter is put 1.5m away from the ground.

The indoor noise come from many elements such as outdoor noise transmitted through enclosure structures, which is the main way; noise transmitted from inside building and other rooms; noise produced by indoor equipments; noise from air-conditioner ventilation system and produced by equipment vibration. In order to minimize effects from noise of other rooms during the experiment, proper measures are taken: close all the doors and windows; turn off all electrical equipments such as computers, sound box and TV sets; ensure that there are no sound of walking and talking in the measurement room.

3. RESULTS

3.1 Data processing method

All the data in this research is processed by statistical software SPSS 13.0. Building A is measured between 1:20 3: 30 AM, 9:50 12:00 AM and 2:55 5: 30 PM. After the data validity is guaranteed, 23105 data groups are collected, including 6485 groups during 1:20 3: 30 AM; 7886 groups during 9:50 12:00 AM; 8734 groups during 2:55 5: 30 PM.

Because of too much data, the changing tendency of noise attenuation from outdoor to indoor is not easy to analyze. Therefore, classification of data processing is taken. Firstly, attenuation sound pressure is got by outdoor sound pressure minus that of indoor sound pressure. In this way, groups of outdoor sound pressure and relative attenuation sound pressure become the object of data processing. Then, define 1 dB (L_A) as unit zone of sound level, such as 55.0dB-55.9dB and 63.0dB-63.9dB. All the group data of outdoor sound pressure and attenuation sound pressure in each unit zone are averaged. However, in order to ensure the data validity, if the number of group data in one sound level zone is less than 50, this sound level zone would be deleted and it couldn't be referred to the next-step data processing.

As the exact relationship between outdoor sound pressure and attenuation sound pressure can't confirm, it is not ensured that which function model should select to analyze. Therefore, curve estimation of SPSS is taken to set up a simple and proper model. Ten regression models are selected as follows.

1. Linear: $Y = b_0 + b_1 \times X$;

2. Quadratic: $Y = b_0 + b_1 \times X + b_2 \times X^2$;
3. Compound: $Y = b_0 \times b_1^X$;
4. Growth: $Y = e^{(b_0 + b_1 * X)}$;
5. Logarithmic: $Y = b_0 + b_1 \times \ln X$;
6. Cubic: $Y = b_0 + b_1 \times X + b_2 \times X^2 + b_3 \times X^3$;
7. S: $Y = e^{(b_0 + b_1 / X)}$;
8. Exponential: $Y = b_0 e^{b_1 X}$;
9. Inverse: $Y = b_0 + b_1 / X$;
10. Power: $Y = b_0 X^{b_1}$

In order to ascertain which function model is more similar to the data, the above ten models of curve estimation are taken. The parameter estimation is done by SPSS automatically, along with the statistic value of R^2 and F. Finally, the regression model, which has the largest value of R^2, could be considered as the best one to describe the outdoor-indoor noise attenuation at that time.

3.2 Forenoon noise attenuation model

As stated above, the measurement time is divided into wee hours, forenoon and afternoon. According to the three time spans, analysis about noise attenuation model is carried out. Table 1 shows the averaged data of forenoon noise attenuation in building A, including outside sound level (Outside), outside-inside sound attenuation (Attenuation) and frequency. The frequency which refers to 54dB~55dB is of the highest frequency, that is, it is the most possible noise that appears in this range.

Table1 Averaged data of noise attenuation in the morning

Outside(dB)	Attenuation(dB)	Frequency
51.51	11.04	332
52.49	11.11	775
53.47	11.39	1043
54.45	11.44	1210
55.43	11.70	1102
56.41	12.13	897
57.43	12.41	723
58.43	12.89	490
59.42	13.24	348
60.43	13.75	230
61.46	14.26	166
62.41	13.56	103
63.48	14.07	74
64.43	14.65	68
65.45	14.79	77
66.42	15.66	60
67.42	16.00	53

Table 2 shows the result of curve estimation of forenoon noise attenuation through ten models. The result of curve estimation of ten models is good, and the modulus of R^2 is above 0.95 via significance value p=0.00. The modulus of linear equation (R^2) is as much as 0.964. That is to say, there exists significant linear relationship between the outdoor-indoor noise attenuation and the outdoor noise in forenoon. The model with biggest R^2 value is exponential equation and growth curve with R^2=0.975. Figure2 displays the curve of linear and exponential model.

The linear model: $Y = -5.278 + 0.311X$

The exponential model: $Y = 3.224e^{0.024X}$

Y refers to outdoor-indoor noise attenuation (dB), while X refers to outdoor sound level (dB).

Table2 Model summary and parameter estimates of forenoon noise attenuation

Equation	Model Summary			Parameter Estimates			
	R Square	F	Sig.	Constant	b1	b2	b3
Linear	0.969	475.983	.000	-5.278	0.311		
Logarithmic	0.964	399.446	.000	-61.612	18.324		
Inverse	0.956	322.930	.000	31.373	-1074.04		
Quadratic	0.973	253.639	.000	10.303	-.217	0.004	
Cubic	0.973	253.822	.000	5.161	0.045	0.000	2.49E-005
Compound	0.975	584.230	.000	3.224	1.024		
Power	0.973	536.960	.000	.044	1.394		
S	0.968	454.334	.000	3.958	-81.833		
Growth	0.975	584.230	.000	1.171	0.024		
Exponential	0.975	584.230	.000	3.224	0.024		

Dependent Variable: outdoor-indoor noise attenuation, Independent variable: outdoor sound level

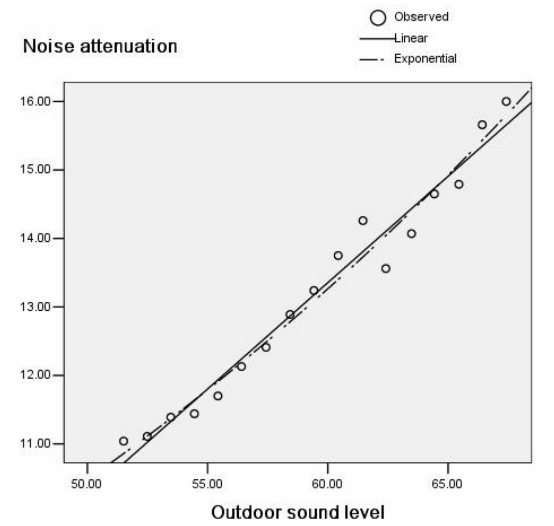

Figure 2: Curve-fitting of linear and exponential model in the morning

3.3 Afternoon noise attenuation model

Table3 demonstrates the averaged data of afternoon noise attenuation in building A. The frequency is in the sound pressure range in afternoon. 54dB~55dB is of the highest frequency unit zone, that is, it is most possible noise that appears in this range, which is the same as forenoon.

Table3 Averaged data of noise attenuation in the afternoon

Outside(dB)	Attenuation(dB)	Frequency
49.56	10.16	55
50.54	10.17	214
51.48	10.38	484
52.5	10.37	832
53.46	10.71	1212
54.45	11.15	1313
55.43	11.45	1266
56.42	11.90	1104
57.43	12.39	825
58.43	12.65	551
59.43	13.40	339
60.42	13.54	216
61.37	13.87	103
62.39	14.93	83
63.36	14.50	51

Table 4 shows the result of curve estimation of afternoon noise attenuation through ten models. The result of curve estimation of ten models is fairly good, and all the modulus of R^2 is above 0.94 via significance value p=0.00. The modulus of linear equation (R^2) is as high as 0.967. That is to say, there exists high significant linear relationship between the attenuation of noise from outdoor to indoor and the outdoor noise in afternoon. The model with biggest R2 value is quadratic equation and growth equation with R^2=0.981. Figure3 shows the curve of linear and quadratic equation.

The linear model: $Y = -8.526 + 0.366X$

The quadratic model: $Y = 28.344 - 0.948X + 0.012X^2$

Y refers to outdoor-indoor noise attenuation, while X refers to outdoor sound level.

Table4 Model summary and parameter estimates of afternoon noise attenuation

Equation	Model Summary			Parameter Estimates			
	R Square	F	Sig.	Constant	b1	b2	b3
Linear	0.967	377.824	.000	-8.526	0.366		
Logarithmic	0.958	293.820	.000	-70.344	20.457		
Inverse	0.946	228.535	.000	32.387	-1138.259		
Quadratic	0.981	304.597	.000	28.344	-0.948	0.012	
Cubic	0.980	297.399	.000	15.695	-0.282	0.000	6.75E-005
Compound	0.976	530.137	.000	2.200	1.031		
Power	0.970	418.197	.000	0.013	1.685		
S	0.961	322.046	.000	4.158	-93.893		
Growth	0.976	530.137	.000	0.789	0.030		
Exponential	0.976	530.137	.000	2.200	0.030		

Dependent Variable: outdoor-indoor noise attenuation, Independent variable: outdoor sound level

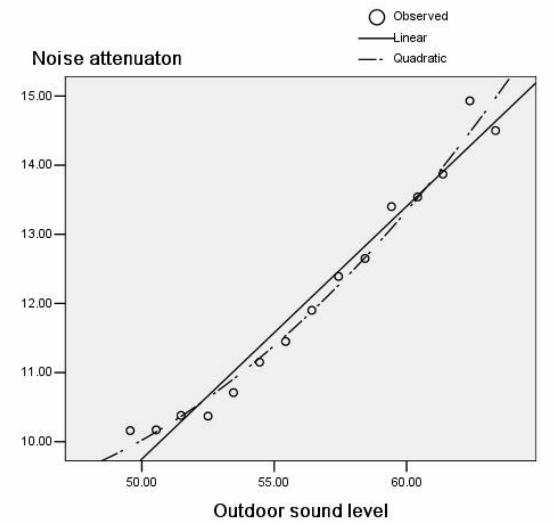

Figure 3: Curve-fitting of linear and exponential model in the afternoon

3.4 Night noise attenuation model

Table5 demonstrates the averaged data of night noise attenuation. 39dB-40dB is unit zone that has the highest frequency. Compared to that of daytime, it deceases by 15dB, which reflects the difference of noise pressure in daytime and at night.

Table5 Averaged data of noise attenuation in the evening

Outside(dB)	Attenuation(dB)	Frequency
34.62	4.90	86
35.48	5.65	265
36.47	6.33	358
37.48	7.08	495
38.47	7.86	628
39.47	8.63	669
40.43	9.08	633
41.41	9.67	597
42.46	10.04	500
43.44	10.59	373
44.41	10.81	324
45.41	11.37	259
46.46	11.75	202
47.43	11.82	148
48.42	12.11	83
49.44	12.81	77
50.35	13.21	51
56.45	23.97	63
57.41	25.46	52
58.43	26.18	64
59.43	26.58	51

Table 6 shows the result of curve estimation of daytime noise attenuation through ten models. The result of curve estimation of ten models is good, and most modulus of R^2 is above 0.90 via significance value p=0.00. The modulus of linear equation (R^2) is as much as 0.917. That is to say, there exists significant linear relationship between the attenuation of noise from outdoor to indoor and the outdoor noise at night. The model with biggest R^2 value is cubic equation, R^2=0.978. R^2 value of quadratic model is a little smaller than cubic equation, R^2 =0.975. Figure 4 displays the curve of linear and cubic equation.

The linear model: $Y = -25.866 + 0.849X$

The cubic model: $Y = 9.459 - 0.0135X^2 + 0.0003X^3$

Table6 Model summary and parameter estimates of night noise attenuation

Equation	Model Summary			Parameter Estimates			
	R Square	F	Sig.	Constant	b1	b2	b3
Linear	0.917	211.087	.000	-25.866	0.849		
Logarithmic	0.877	135.969	.000	-133.075	38.33		
Inverse	0.829	92.0677	.000	50.667	-1681		
Quadratic	0.975	352.537	.000	37.890	-1.931	0.030	
Cubic	0.978	397.302	.000	9.459	0	-0.0135	0.0003
Compound	0.970	613.031	.000	0.663	1.064		
Power	0.965	528.933	.000	0.000	2.873		
S	0.951	365.063	.000	5.328	-128.6		
Growth	0.970	613.031	.000	-0.411	0.0624		
Exponential	0.970	613.031	.000	0.663	0.0624		

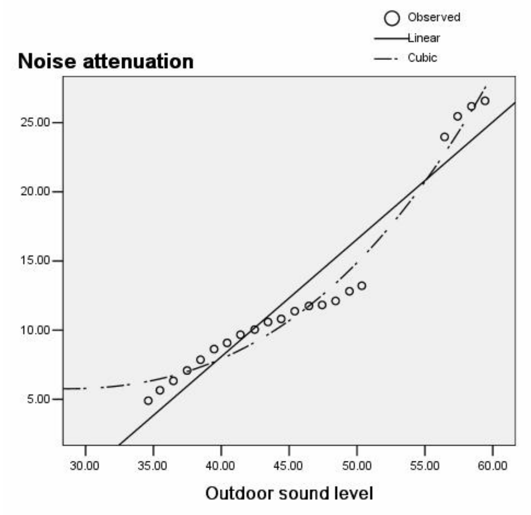

Figure 4: Curve-fitting of linear and exponential model at night

4. CONCLUSION

After compared the R Square of ten equations, it is concluded that the quadratic equation is the best model to describe the outdoor-indoor noise attenuation with R>0.97 at all the three different time. Furthermore, 54dB~55dB is of the highest frequency unit zone both in the morning and afternoon, while at night, the unit zone that has the highest frequency deceases by 15dB.

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