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Relationship between traffic noise resistance and village form in China

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Abstract

The aim of this study is to determine methods to reduce traffic noise levels and to enlarge quiet areas in the rural residential areas in China by controlling relative locations and urban morphological parameters. Six urban morphological parameters, including complete aspect ratio (CAR), landscape shape index of buildings (LSI_B), patch density (PD), road length fraction (RLF), road intersections fraction (RIF), and landscape shape index of roads (LSI_R), are selected and developed. The relationships of the urban morphological parameters to the spatial noise level attenuation and the size of noisy areas were subsequently determined. The effects of motorway horizontal distances and orientations are considered based on spatial traffic noise attenuation. The results indicate that the effect of distance on traffic noise level attenuation is significant and varies widely among the 60 sites studied. A distance of more than 600 m can make the acoustic environment suitable as residential areas. Changing the orientation relationship between the village and the motorway is not always effective for increasing the traffic noise resistance of villages. The results highlight the importance of using urban morphology to improve the traffic noise resistance of rural residential areas; LSI_B and LSI_ R are the most important parameters that correlate to the traffic noise attenuation of motorways.

Keywords: Cold region; Village; Urban morphology; Noise attenuation; Traffic noise

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Introduction

A growing body of literature indicates that continued exposure to road traffic noise is detrimental to human health and well-being, including increased risk of ischaemic heart disease, sleep disturbance, cognitive impairment among children, annoyance, stress-related mental health risks, and tinnitus [Brink, 2011; Di, Liu, Lin, Zheng, & He, 2012; Fyhri & Aasvang, 2010; WHO, 2011]. Studies also indicate that the significance of quietness and quiet areas benefit human health [Booi & van den Berg, 2012; Shepherd, Welch, Dirks, & McBride, 2013]. For many urban residents, a major source of environmental noise is road traffic noise. The main populations seriously affected by this noise are the residents of areas close to highways and large arterial roads.

To reduce the nuisance of traffic noise and to enlarge quiet areas in cities, solutions have been suggested, including improving/optimising roadway traffic loads, number of lines, road surface types and vehicle speed [Avsar & Gonullu, 2005]; designing noise barriers for propagation outdoors [Renterghem et al., 2015], and designing buildings with higher noise reduction capabilities, such as building facades and balcony improvements [Kim & Kim, 2007; Lee, Yong, Jin, & Song, 2007]; and designing buildings and courtyards with green plants [Gidlöf-Gunnarson & Őrhström, 2010; Kim, Yang, & Kang, 2014; Renterghem & Botteldooren, 2009; Veisten et al., 2012; Wong, Tan, Tan, Chiang, & Wong, 2010; Yang, Kang, & Choi, 2012]. Soundscape studies have recently focused on ecologically improving soundscapes as a method to reduce urban noises and enlarge quiet areas [Jeon, Lee, You, & Kang, 2010].

The effect of urban morphology on traffic noise propagation has been studied in terms of spatial structure (e.g., building layout) and certain urban morphological parameters (e.g., building density) to verify the method of simplifying noise mapping by examining the effects of building gaps. Kang compared the attenuation of broadband sound among different street patterns with particular reference to three building configurations, simulating the typical UK housing types of detached, semidetached and terraced houses [Kang, 2007]. The spatial distribution of traffic noise in a city is related to traffic volume, building density, shape of the building blocks and general urban form has been determined using numerical calculations of the data from Amsterdam and Rotterdam, for various idealized urban designs [Salomons & Pont, 2012], and from Greater Manchester in the UK and Wuhan in China, which have low and high average urban densities, respectively, for a number of typical urban areas [Wang & Kang, 2011]. Three examples of studies focusing on how urban morphology influences the sound environment in low-density residential areas are the studies by Hao and Kang, who examined whether and how urban morphology influences the capability of attenuating traffic noise levels [Hao, Kang, Krijnders, & Wörtche, 2015], the influence of urban morphology on spatial noise level attenuation of flyover aircrafts [Hao & Kang, 2014], and how to increase birdsong loudness and the visibility of green areas by controlling urban morphological parameters [Hao, Kang, & Krijnders, 2015]. In a wider context, urban morphology, which pertains to the spatial structure and characteristics of a metropolitan area, city, town, or village, has been widely studied regarding urban settings, particularly the characteristics of atmospheric environment (e.g., air quality and wind environment) [Borrego et al., 2006; Edussuriya, Chan & Ye, 2011; Golany, 1996; Ng, Yuan, Chen, Ren, & Fung, 2011; Oke, 1988; Soulhac, Mejean, & Perkins, 2001], renewable energy (solar energy) [Compagnon, 2004; Robinson, 2006; Sarralde, Quinn, Wiesmann, & Steemers, 2015], and the urban heat island effect [Brian, 2004; Brian & Michael, 2001; Touchaei & Wang, 2015]. Other factors extensively examined using a series of quantitative urban morphological parameters include those on street layout and coverage as well as landscaping [Geoghegan, Wainger & Bockstael, 1997; Liu, Kang, Behm & Luo, 2014; Stephen, 2004; Val, Atauri & Lucio, 2006].

However, despite these research efforts, noise reduction in rural residential areas is still primarily achieved using noise barriers. The relationship between road traffic noise and the characteristics of village form planning still needs to be analysed in detail. Few studies have considered how to improve the traffic noise resistance of villages by systematically controlling a set of urban morphological parameters, especially considering the rural residential areas in less developed regions such as those in China. At the end of 2014, the Chinese expressway with a total mileage of 112000 kilometres opened to traffic, becoming the world's largest motorway system. Moreover, China has a large rural population with high density; thus, many villages are located on or near a well-travelled motorway. These villages are no longer quiet places, and new villages have expanded in locations adjacent to the motorway for economic or other reasons.

Therefore, this study aims to examine the influence of different effects of location, such as distance and orientation between a village and the motorway, and to explore methods to integrate the effects of urban morphological parameters to improve the traffic noise resistance of rural residential areas in China. To analyse these parameters, a series of noise mapping was performed for selected typical villages.

2. Methodology

2.1. Case study sites

Since the "Eleventh Five-year" Plan for Developing Socialism New Rural Areas was proposed, village development has received unprecedented attention in China. Over the past several decades, the living standards of villages have improved rapidly. It is important to note that the village classifications in this study refer to homes for living and various productions of the villagers according to the “Environmental Quality Standard for Noise” (GB3096-2008).

The village sites in this study were chosen in Heilongjiang because it is the major grain-producing area in the flat terrain with a planting area that accounts for 83.5% of the province’s total and a rural population that accounts for 43.1% of the province's total, according to the Heilongjiang Statistical Yearbook (2014). Heilongjiang has a transportation network composed of a motorway and hierarchical traffic roads throughout the province, as shown in Fig. 1, which generate widespread traffic noise.

Figure. 1. Locations of the study sites.

Due to the cold climate and lagging economic situation in the villages of Heilongjiang, there are very diverse village forms with low-rise and low-density residential zoning plans. Therefore, 60 villages sites located along the Harbin-Tongjiang section of the G1011 motorway in Heilongjiang were chosen for site samplings as typical villages in the cold region of China. These sample villages that were each located along one kilometre of G1011 from Harbin, Jiamusi and Shuangyashan were numbered H1-H30, J1-J16, and S1-S14, respectively. The conditions of the building façades and of the ground were obtained from in situ investigations and Google Maps. CAD software was used to describe the spatial morphology of the villages and their relationship with the surrounding G1011motorway, as shown in Fig. 2.

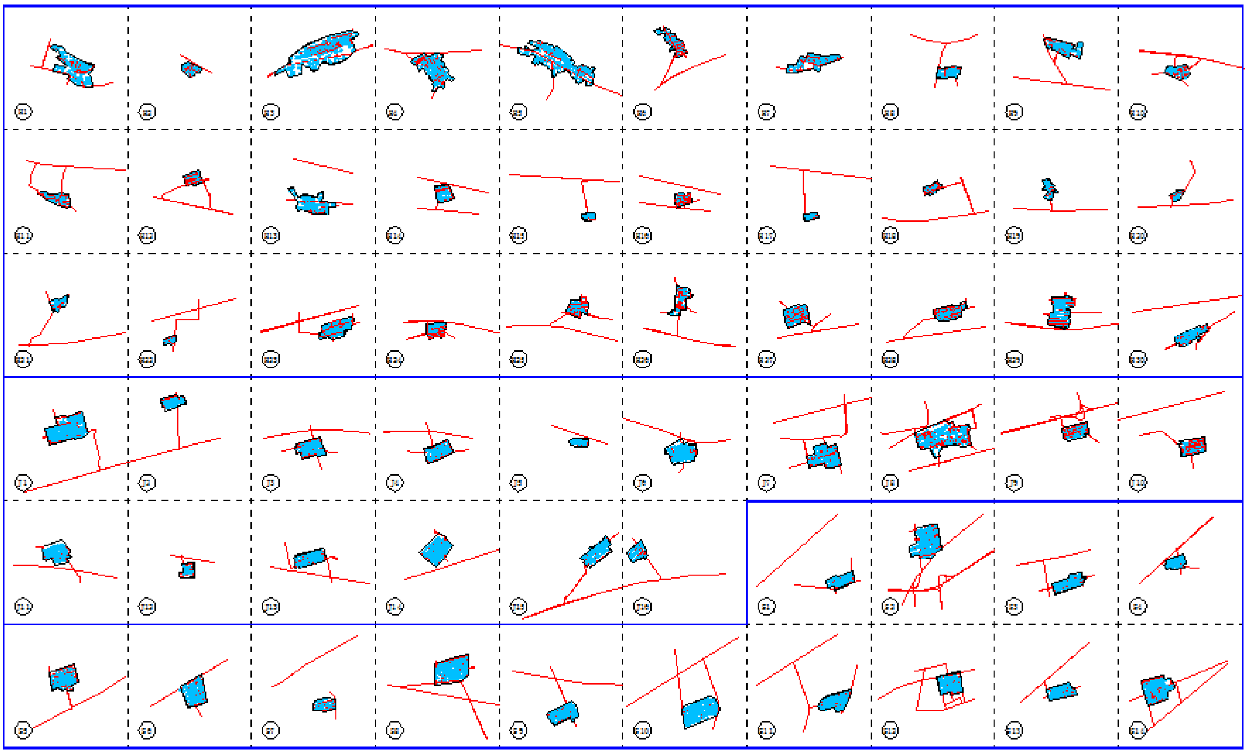


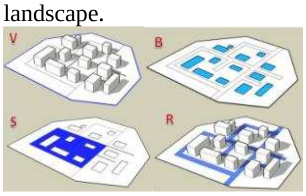
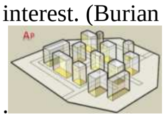
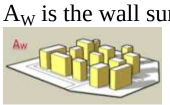
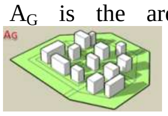
Figure. 2. CAD of the village sites based on Google Maps. Scale 1:1000.

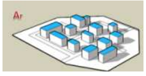
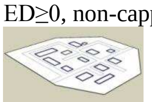
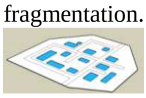
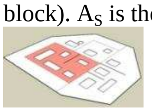
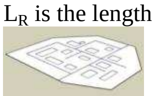
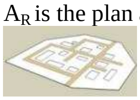
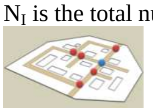
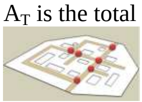
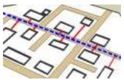
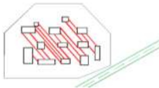
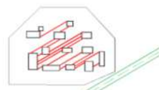
2.2. Selection and calculation of urban morphological parameters

To obtain a comprehensive description of the village form in cold regions, this study used 18 quantitative morphological parameters from previous studies that explored, developed, and studied diverse urban morphology. The parameters include all of the factors that are likely related to traffic noise resistance based on the potential effects of urban morphology on outdoor sound propagation, such as distance from the source to the receiver, ground effects, the barrier effect, and the canyon effect [ISO 9613-2; Kang, 2007]. The 18 quantitative parameters include the following: Landscape shape index of roads (LSI_R), Building Plan Area Fraction (BPAF), Road length Fraction (RLF), Road Area Fraction (RAF), Road intersections fraction (RIF), and Distance of First-row Building to Road (DFBR). These six parameters chiefly concern geometrical divergence and ground effects. Landscape shape index of buildings (LSI_B), Complete Aspect Ratio (CAR), Building Surface Area to Plan Area Ratio

(BSAPAR), Patch density (PD), Height-to-Width Ratio which vertical to the road direction (HWR_V) and Height-to-Width Ratio which parallel to the road direction (HWP_P) concern barrier attenuation, screening, and reflection. The final six parameters chiefly concern the village planning forms: Landscape shape index of villages (LSI_V), Landscape shape index of street blocks (LSI_S), Edge Density (ED), Largest patch index (LPI), Cell Ratio (CR), and T-ratio (TR). The definitions and calculations of these parameters are shown in Table 1. In a study by Salomons and Pont (2012), the Spacematrix, a three-dimensional representation of urban density, was used, and multiple dimensional representations of building and road were used, such as for building density (i.e. CAR, BPAF, BSAPAR, ED and PD) and for road density (i.e. RLF and RAF). In Hao et al., study 2015b, it was noted that the height-to-width ratio (i.e., the street aspect ratio) is calculated by assuming an ideal situation; sites with multiple buildings utilize an average height-to-width ratio calculated by the average building height divided by the average width between buildings. In this study, the width dimensions between rural buildings were decomposed into vertical and parallel aspects based on the direction of the motorway.

Table 1. Formula for the calculations of the 18 urban morphological parameters.

Parameter	Definition	Formula	Notes	Range
LSI_V	Landscape shape index of villages	$LSI=\frac{0.25E}{\sqrt{A}}$	E is the total circumference boundary of interest. A is the total plan area of the region of interest. LSI reflects the shape complexity of the whole landscape. 	0.984-1.870
LSI_B	Landscape shape index of buildings			5.824-24.103
LSI_S	Landscape shape index of street blocks			0.000-2.117
LSI_R	Landscape shape index of roads			6.688-25.420
BPAF	The ratio of the plan area of buildings to the total surface area of the study region	$BPAF=A_p/A_T$	Ap is the plan area of buildings at ground level, and A_T is the total plan area of the region of interest. (Burian et al., 2005)  .	0.069-0.224
CAR	The summed area of buildings and exposed ground divided by the total surface area of the study region .(Voogt & Oke,1997)	$CAR=A_C/A_T = \frac{A_w + A_r + A_G}{A_T}$	A_C is the combined surface area of the buildings and exposed ground,  A_W is the wall surface area, Ar is the roof area,  A_G is the area of the exposed ground  (Burian et al., 2005). CAR>1.	1.113-1.253

Parameter	Definition	Formula	Notes	Range
BSAPAR	The sum of building surface area divided by the total surface area of the study region	$BSAPAR = \frac{A_r + A_w}{A_T}$	Ar is the plan area of rooftops, A_W is the total area of non-horizontal roughness element surfaces (e.g., walls). (Burian et al., 2005) 	0.182-0.467
ED	The ratio of total length of all patch boundaries to the total patch area.	$ED=10^6 \frac{E}{A}$	ED≥0, non-capped 	0.193-0.391
PD	Patch density	$PD=10^6 \frac{N}{A}$	Patch density has the same basic utility as number of patches as anindex but facilitates comparisons among landscapes of varying size. It is used as a measure of landscape fragmentation. 	0.039-0.143
LPI	Largest patch index	$LPI = \frac{A_S}{A_T}$	Largest patch index quantifies the percentage of total landscape area (plan area of the region of interest) composed of the largest patch (street block). A_S is the largest street block area. 	0.000-0.403
RLF	Road length fraction	$RLF= \frac{L_R}{A_T}$	L_R is the length of the roads at ground level 	0.007-0.023
RAF	Road area fraction	$RAF= \frac{A_R}{A_T}$	A_R is the plan area of roads at ground level 	0.030-0.128
CR	Cell Ratio (Stephen,2004)	$CR = \frac{N_{CE}}{N_{CE} + N_{CU}}$	N_{CE} is total number of cells. N_{CU} is the total number of cul-de-sacs. 	0.000-1.000
TR	T-ratio (Stephen,2004)	$TR= \frac{N_T}{N_I}$	N_T is the total number of T-junctions. N_I is the total number of junctions. 	0.000-1.000
RIF	Road intersections fraction	$RIF= \frac{N_I}{A_T}$	N_I is the total number of road intersections. A_T is the total plan area of the region of interest. 	0.125-1.506
DFBR	The mean of the distances from the front façades of the first row of buildings to the road	$DFBR = \frac{1}{n}\sum_{i=1}^{n} d_i$	n is the total number of first-row buildings, and d_i is the distance from the first-row buildings to the road. 	9.604-42.393
HWR_V	The average of the building heights(Havg) is divided by the average of the horizontal distances between two adjacent buildings	$HWR(\theta)= \frac{H_{avg}}{S_{avg}}$	θ is the direction vertical to the road direction. 	0.053-0.162
HWR_P			θ is the road direction 	0.055-0.256

Considering the possible inherent relationships among the 18 parameters, a bivariate analysis was conducted to determine their independence, as shown in Table 2. The results indicate that there is a broad and complex connection between the 18 parameters. The relevant parameters were extracted and further analysed using principal component analysis (PCA) and sensitivity analysis to ultimately select six parameters: CAR, LSI_B, PD, RLF, RIF, and LSI_R.

Table 2. Relationships between the urban morphological parameters in terms of R^2 values of second-order polynomial regression, where * indicates the p<0.05 level (2-tailed) and ** indicates the p<0.01 level (2-tailed) in the Spearman's rho correlation.

	LSI_V	**BPAF**	**CAR**	**BSAPAR**	**LSI_B**	**PD**	**ED**	**LPI**	**LSI_S**	**RLF**	**RAF**	**RGUF**	**TRIR**	**RIF**	**LSI_R**	**DFBR**	**HWR_P**	**HWR_V**
LSI_V	1																	
BPAF	.198	1																
CAR	-.131	**.602****	1															
BSAPAR	.028	.877**	**.877****	1														
LSI_B	.176	-.014	.097	.012	1													
PD	**-.265***	**.323***	**.840****	**.655****	.133	1												
ED	**-.307***	**-.709****	.028	**-.360****	.121	**.299***	1											
LPI	-.133	.012	.101	.081	-.117	.230	.135	1										
LSI_S	-.055	-.046	-.042	-.044	.224	.091	-.026	**.451****	1									
RLF	**-.390****	-.196	.168	-.008	-.022	**.337****	**.323***	**.295***	**.317***	1								
RAF	**-.289***	-.147	.180	.040	.048	**.354****	**.297***	**.333****	**.273***	**.903****	1							
RGUF	**-.262***	-.081	.112	.043	.183	.209	.199	**.546****	**.467****	**.573****	**.515****	1						
TRIR	.135	**.295***	-.066	.135	**-.326***	-.180	**-.371****	.069	-.012	**-.276***	-.237	-.015	1					
RIF	**-.392****	-.073	.232	.107	.030	**.309***	.210	**.255***	.253	**.804****	**.737****	**.599****	-.112	1				
LSI_R	-.012	-.218	-.091	-.214	**.842****	.024	.139	-.101	**.356****	**.297***	**.265***	**.337****	**-.403****	.248	1			
DFBR	.071	-.196	**-.297***	**-.307***	.004	**-.388****	-.065	.004	.210	-.160	**-.255***	-.090	-.106	-.192	.046	1		
HWR_P	.085	.143	**.386****	**.287***	**-.406****	.246	.117	-.024	**-.307***	-.010	-.024	-.089	**.310***	.040	**-.451****	-.196	1	
HWR_V	-.182	**.622****	**.768****	**.790****	-.248	**.601****	-.133	.136	-.226	.121	.164	.020	.124	.145	**-.392****	**-.411****	**.446****	1

2.3. Noise mapping

To simulate the spatial traffic noise distribution in the sites, noise maps were calculated using a commonly used noise-mapping package, Cadna/A [DataKustik, 2006]. The accuracy of the calculation was validated by the measurements in the village of northeast China. Although calculation errors were relatively higher at few measuring points which are far away from the sound source, the average calculation error is less than 2 dBA [Mei, 2014; Meng, 2014]. The low-density of the village is the main reason for the 2 dBA error, as there are mostly direct sounds emitted by the highway traffic noise and few reflections on the sites. The noise maps were generated with the building information of the sampled grids, using the grid calculation 10 m x 10 m, and then the calculated grids data were exported to Excel for further analysis. In this study, Ln (Lmax, Lavg, Lmin, L10-L90) are not based on the conventional time domain, but on the spatial domain. Ln are obtained from all the spatial noise level values for each site which are arranged in a descending order. For example, Lmax, Lavg and Lmin denotes the highest value, the mean value and the lowest value of all the spatial noise levels of a given site, respectively, where n in Ln specifies one certain sound level value at the position of n% in all of the descending values. For example, L90 is the value located at the top 90% in the rankings of all the spatial noise level values [Wang & Kang, 2011; Hao et al., 2015b].To investigate the significance of the number of reflections in a village environment, three villages were chosen from the 60 sites for analysis, considering the maximum, the median, and the minimum of Patch density (PD) by the number of 0.098, 0.074 and 0.052, respectively, and it is noted that the Floor Area Ratios of the three sampled sites are 0.124, 0.098 and 0.069, respectively. Hence these three villages may be considered as typical, low-density village in northeast China. With the change of the reflection numbers for simulation analysis, Lavg in villages had little increase (0.39-0.78dBA) with increasing reflection order from 1 to 6. The validity of less reflections is mainly because the distances between buildings are generally great and the height of buildings is general low, so the diffraction of sound occurs around the buildings is not that important. Comparing the calculation time with various reflection orders, it was shown that the increase in calculation time with increasing reflection order is approximately exponential. Considering both accuracy and efficiency, this paper used a reflection order of 2.

According to the investigation of the countryside, almost all of the rural buildings are one-story buildings with a pitched roof in Heilongjiang, indicating a typical, low-rise residential rural morphology. Kang suggested that an additional height of $\Delta = 0.7$ m above the eave height is a good approximation for simplifying pitched roofs to reduce the time for model construction and calculation [Kang, 2007]. Therefore, in this study, 4.5 m was established as a generic height for this type of morphology, which increased the calculation speed for this study [Meng, 2014]. The traffic volume dates of the motorway and rural road conform to the “Design Specification for Highway Alignment” (JTG D20-2006). This study just considers the motorway outside the villages to examine the influence of different relative locations, such as distance and orientation between a village and the motorway. It is assumed that the traffic volume of a motorway is 30000 cars per day. In the study 20 orientation relationships between village and motorway were considered by rotating the motorway clockwise, with the north-south motorway on the west side of the village as a starting rotation orientation of 0°.

To determine the situation of traffic noise at the village sites along the motorway, the traffic volume data of the motorway were set to 15000 cars per day; the single-lane and two-lane rural routes were set to 400 cars per day and 1000 cars per day, respectively. The results show that the noise environments differ widely among village sites. Based on the results of the noise maps, the open areas were categorised into three groups in terms of the noise level ranges: SPL (L_{Aeq}) ≤50 dBA (quiet area), 50-60 dBA (less noisy area), and SPL (L_{Aeq}) >60 dBA (noisy area). In Meng's (2014) study, based on field measurements and questionnaire surveys about road traffic noise with 13 typical villages in the northeast of China, it was found that the village residents would feel uncomfortable when the average sound pressure level of main road traffic noise is too high (≥60 dBA) or too low (＜50 dBA). Consequently, in the present study the value of 50 dBA is used to characterise the quiet areas for the villages in terms of noise from the outside motorway. The use of 50dBA is also in line with the current noise evaluation criteria for night time in class-2 standard ("Environmental Quality Standard for Noise"GB3096-2008). However, because quiet areas are defined in qualitative rather than quantitative terms, the concept of a "quiet area" in this study only presents a relative rather than absolute definition of a quiet area, namely, relatively low transport related levels (daytime) even though 50dB is still high when it concerns night time noise levels. As the traffic volume was at a minimised level, namely 15000 cars per day, the mean percentages of the categories of the 60 study sites were 3.8% (quiet area), 42.9% (less noisy area), and 53.3% (noisy area). The mean L_{avg} of the 60 villages was 60.5 dBA, and the background noise L_{90} was 53.8 dBA–61.8 dBA.

3. Results

3. 1. Effect of distance between village and motorway

To examine the influence of the distance between the village and motorway on noise attenuation, the traffic noise attenuation of the 60 sites was compared among seven distances to site, i.e., 0 m, 30 m, 60 m, 100 m, 300 m, 600 m, and 1000 m, in terms of L_{10}. As expected, increasing the distance can be effective for reducing the traffic noise, however, it is interesting to note that the distances have tremendously different effects on traffic noise attenuation among the 60 sites. When the distance was increased from 0 to 30 m, 60 m, 100 m, and 300 m, the largest decrease in L_{10} was for village H16, which was reduced by 6.8 dBA, 8.4 dBA, 10.2 dBA, and 15.2 dBA, respectively; the smallest decrease was for village H3, which was reduced by 0.7 dBA, 1.4 dBA, 2.3 dBA, and 5.9 dBA, respectively. When the distance was increased to 600 and 1000 m, village H2 decreased the most, with a reduction of 20.8 dBA and 26.2 dBA, respectively; village J8 decreased the least, with a reduction of 9.8 dBA and 14.1 dBA, respectively. This result is feasible because the differences in the village forms affect the traffic noise attenuation due to increasing the distance. Improving the acoustic environment of the rural residential areas near the motorway requires not only increasing the distance between the villages and the motorway but also considering the impact of the village form.

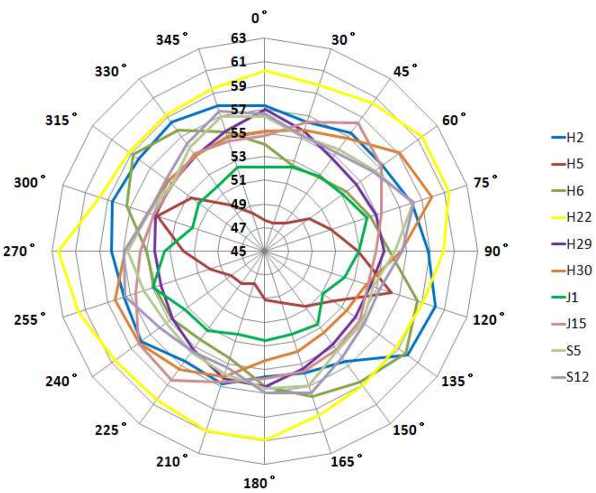
Table 3 shows the relationships between the mean traffic noise level variances among the 60 sites and the horizontal distance between the site and the motorway. When the distance is smaller than 100 m, for each additional 30 m increase, “noisy areas” decrease by approximately 5%; when the distance is at least 300 m, the “noisy areas” in village sites are 0%; and when the distance is greater than 1000 m, L_{max} <50 dBA and “quiet areas” reach 100%. In the 60 village sites, 20 sites are located less than 100 m from the motorway and 33 sites are located less than 300 m from the motorway, causing the acoustic environment to fail to meet the class-2 standard in China. Only 15 villages are located more than 600 m from the motorway, making the acoustic environment to meet the class-1 standard, which shows the seriousness of the traffic noise problem in the villages of China.

Table 3. Variances of the mean traffic noise level among the 60 sites, with horizontal distances between the site and motorway of 0 m, 30 m, 60 m, 100 m, 300 m, 600 m, and 1000 m.

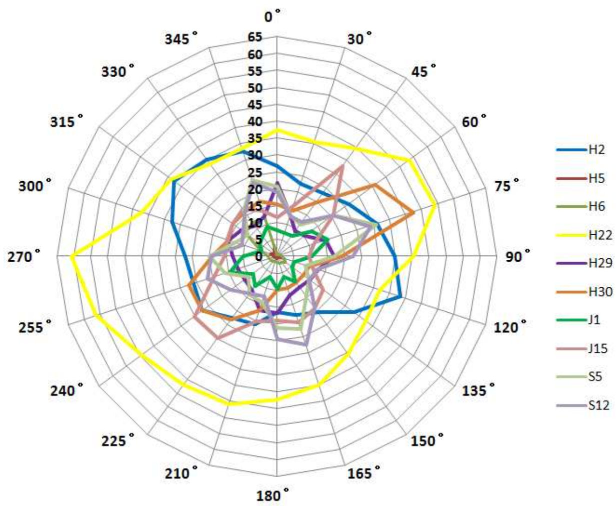
Distance （m）	**Noise area categories (%)**			**Spatial noise level indices ln(dBA)**										
	Quiet area	**Less Noise Area**	**Noisy Area**	**Lmax**	**L10**	**L20**	**L30**	**L40**	**L50**	**L60**	**L70**	**L80**	**L90**	**Lmin**
0	6.67	67.42	25.92	83.44	64.71	61.13	59.02	57.56	56.39	55.42	54.54	53.59	52.15	37.27
30	7.73	70.03	21.24	70.58	62.92	59.93	58.12	56.79	55.73	54.86	54.01	53.08	51.60	36.68
60	9.34	74.42	16.24	67.26	61.56	58.84	57.24	56.07	55.10	54.28	53.46	52.54	51.03	36.02
100	11.85	77.78	10.37	64.76	59.95	57.58	56.22	55.18	54.32	53.57	52.77	51.85	50.31	35.25
300	31.00	68.97	0.00	57.59	55.11	53.71	52.79	52.04	51.37	50.72	50.01	49.13	47.45	32.29
600	81.86	18.14	0.00	52.31	50.67	49.69	48.98	48.37	47.80	47.24	46.63	45.78	44.04	28.96
1000	100.00	0.00	0.00	47.29	46.05	45.31	44.75	44.24	43.75	43.27	42.73	41.98	40.26	25.52

3.2. Effect of orientation between village and motorway

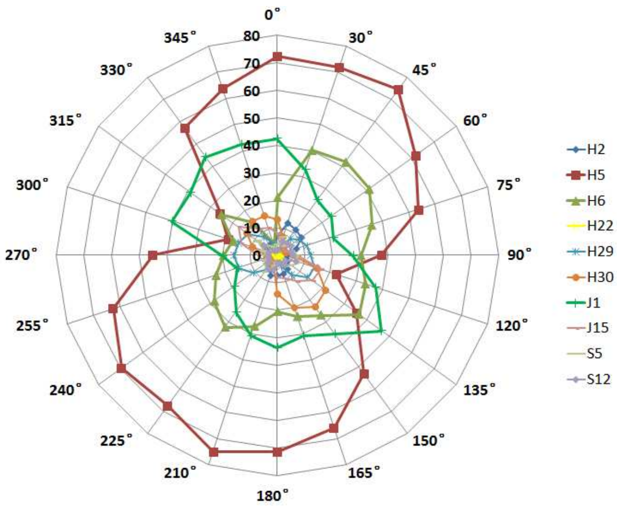
To explore the influence of the orientation between the motorway and village on the traffic noise resistance of the sites, the spatial noise level (L_{avg}) and the noise area categories (“noisy area”, “quiet area”) of 20 orientations in 10 typical villages are presented in Fig. 3a-c. It is important to note that manual selection was used to choose the typical sites by eliminating the 60 sites with similar morphologies to the others. The exclusion was performed to obtain the representative residential morphology characteristics of the northeast villages in China. Ten villages were chosen from the 60 sites for analysis, which contain the maximum, the minimum, and the median of each of the 18 urban morphological parameters;



(a) Spatial noise level indices $\mathbf{L_{avg}}$



(b) Noisy areas



(c) Quiet areas

Figure 3. Variances of spatial traffic noise attenuation Lavg and the sizes of the “noisy areas” and “quiet areas” with changing orientation relationships between the sites and the motorway.

In Figs. 3a-c, it can be seen that the villages were divided into isotropic and anisotropic types in terms of L_{avg}, "noisy area", and "quiet area". The isotropic villages are only slightly affected by the changing orientation relationship between the motorway and village. For example, as shown in Fig. 3a, H29 is the village with the least variation (2.7 dBA) in terms of L_{avg} among the isotropic villages, i.e., J1, S5, S12, H2, H22, H29, and J15, all of which have variations of less than 5 dBA. In Fig. 3b, village H5 changed in only 3% of the 20 orientation relationships in terms of "noisy areas"; from Fig. 3c., it can be seen that in terms of "quiet areas", village H22 has the least variation (2.3%) among the isotropic villages i.e., H22, S5, H2, and S12, all of which have variations of less than 10%.

To investigate significance of the orientation effect on an anisotropic village, as in Fig. 3a, radar maps show the differences among 20 orientations in each of the 10 villages. The anisotropic villages are strongly affected by the changing orientation relationship between the motorway and the village. For example, villages H5, H6, and H30 present a distinct oval pattern, with orientations of 90°, 105°, and 75°, L_{avg} that varied by 8.8 dBA, 7.1 dBA, and 6.4 dBA, respectively. Fig. 3b shows that except for village H5, nine anisotropic villages changed with more than 10% of the 20 orientation relationships in terms of "noisy areas". H30 is the village with the largest decrease of 32.8% by turning from 75° to 135°, followed by H2, H22, J15, and S5 with decreases of 21.7%, 29.0%, 23.6%, and 22% of "noisy areas" for orientations of 60°, 150°, 45°, and 45°, respectively. Villages H6, H29, J1, and S12 changed by 11.8%, 12.5%, 10.8%, and 18.1% for orientations of 30°, 45°, 135°, and 135°, respectively. Therefore, the orientation relationship between the motorway and the village significantly affected the "noisy areas". From Fig. 3c, it can be seen that villages H5, J1, H6, H30, J15, and H29 changed the "quiet areas" by more than 10%; for example, H5 had the largest increase of 54.6% by turning from 300° to 210°, followed by H6, H30, and J1 with increases of 37.8%, 20.2%, and 31.2% in "quiet areas" for orientations of 60°, 90°, and 125°, respectively. Villages H9 and J15 had 13.8% and 14.9% increases in the "quiet areas" for orientations of 90° and 105°, respectively. Therefore, only some of the villages were significantly affected by the changing orientation relationships.

Furthermore, using "1" to represent less than or equal to the mean value and "2" to represent greater than the mean value of the acoustic variable among the 20 orientation relationships of the 10 typical villages, the frequency value of "1" in terms of L_{avg} and “noisy areas” and "2" in terms of “quiet areas” can be used to determine the best and the worst orientation relationships, where higher values indicate better acoustic environments and lower values indicate worse acoustic environments. As shown in Fig. 4, there were alternately better and worse orientation relationships. The better regions were much fewer than the worse regions. Adopting orientations of 30°, 120°–135°, and 315° may create better acoustic environments, while orientations of 75°–90°, 180°, 255°–270°, and 345° may worsen the acoustic environments. The reason for this finding might be that the barrier effects of buildings and the sound propagation through the roads are strongly influenced by the orientation relationship between the motorway and village.

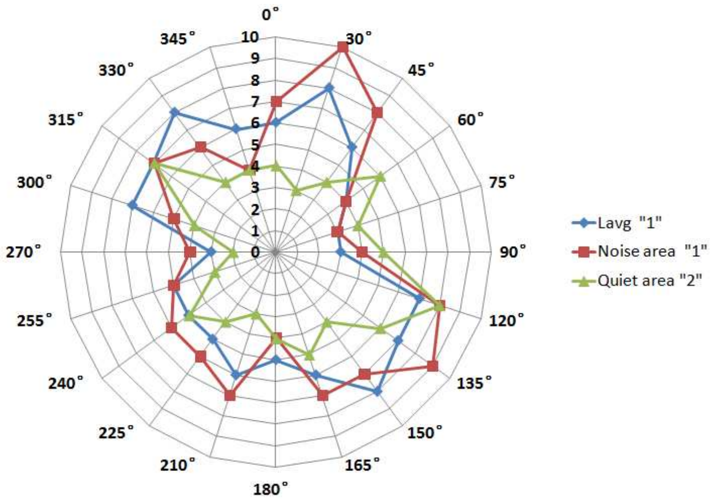


Figure 4. Variances of traffic noise resistance of the 20 orientation relationships in the 10 typical villages, comparing the frequency value of “1” in terms of L_{avg} and “noisy area” and of “2” in terms of “quiet area”.

3. 3. Relationships between “noisy areas” in villages and urban morphological parameters

Six urban morphological parameters and two noise area categories were selected (see Sections 2.2 and 2.3, respectively) to examine possible relationships between village form and spatial traffic noise attenuation. A correlation analysis (Spearman’s rho) was performed (see Table 4). It is important to note that LSI_B and LSI_R have significant correlations with the noise area categories indices ($p<0.01$, 2 tailed) under the conditions of varying distance between the sites and the motorway. The statistical data of RLF and RIF, however, have no correlation with any of the indices, suggesting that road length and the number of road intersections have limited influence on traffic noise level under any conditions of varying distance between the site and the motorway.

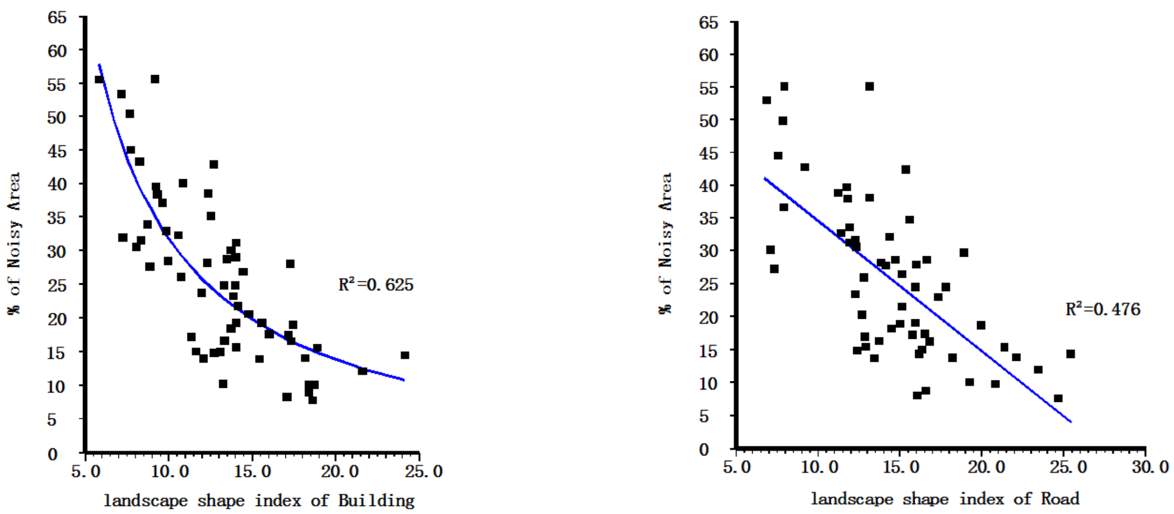
Table 4. Spearman's rho correlations between the noise area category indices in the villages and the urban morphological parameters (2-tailed). Significant correlations are marked with * ($p<0.05$) and ** ($p<0.01$).

Distance（m）	**Indices （%）**	**Urban Morphological Parameters** CAR	LSI_B	PD	RLF	RIF	LSI_R
0	**Quiet area**	-.085	**.751****	-.103	-.201	-.093	**.682****
	Noise area	.181	**-.756****	.145	.135	.063	**-.719****
30	**Quiet area**	-.053	**.667****	-.095	-.064	-.015	**.652****
	Noise area	.209	**-.568****	.205	.083	.051	**-.590****
60	**Quiet area**	-.056	**.657****	-.109	-.076	-.019	**.644****
	Noise area	.235	**-.528****	.232	.107	.070	**-.542****
100	**Quiet area**	.014	**.641****	-.054	-.075	-.015	**.624****
	Noise area	**.276***	**-.485****	**.264***	.125	.120	**-.496****
300	**Quiet area**	.016	**.593****	-.077	-.012	.064	**.605****
600	**Quiet area**	-.152	**.477****	-.242	-.156	-.058	**.482****

The tendencies of "noisy areas" with varying LSI_B and LSI_R are further illustrated in Fig. 5, which shows the distance of 0 m because these variances are higher than those of 30 m, 60 m, and 100 m. It can be seen in Fig. 5 that when either LSI_B or LSI_R increases, the size of the noisy area in the village decreases. Specifically, in Fig. 5a, the inverse regression analysis results show that when LSI_B increases, the "noisy area" sharply decreases by 39% and then slightly decreases by 9%; the reason for this result might be that the increased building complexity in the rural residential area induces more sound reflections between buildings, further reducing the barrier effect of the buildings. By comparing the forms of 60 sites with different LSI_B values, the tiny and neat villages may have poor noise resistance, while large, hybrid, or combination layouts of the rural residential areas with multi-layer pluralistic forms of courtyard space may be beneficial to reducing noisy areas.

Fig. 5b shows the results of a linear regression analysis: a greater value of LSI_R indicates smaller noisy areas of the village. This relationship could be because the increased complexity of the road system in the rural residential area causes less sound propagation through streets along the roads. Because the value of R^2 is less than 0.5, a stepwise multiple regression analysis was performed between two noise area categories and other urban morphological parameters that are potentially related to "noisy areas".

The results show that there are two variables related to “noisy areas” with R^2=0.570. The most effective variable was LSI_R, (-0.817), and the other was RAF (0.331), which has a positive relationship; this result could be linked to less dense roads areas of the rural residential area causing less sound propagation through the road. “Noisy area” has a negative relationship with LSI_R and has a positive relationship with RAF, which suggests its relationship with smaller road widths and lower numbers of roads running straight through the village.

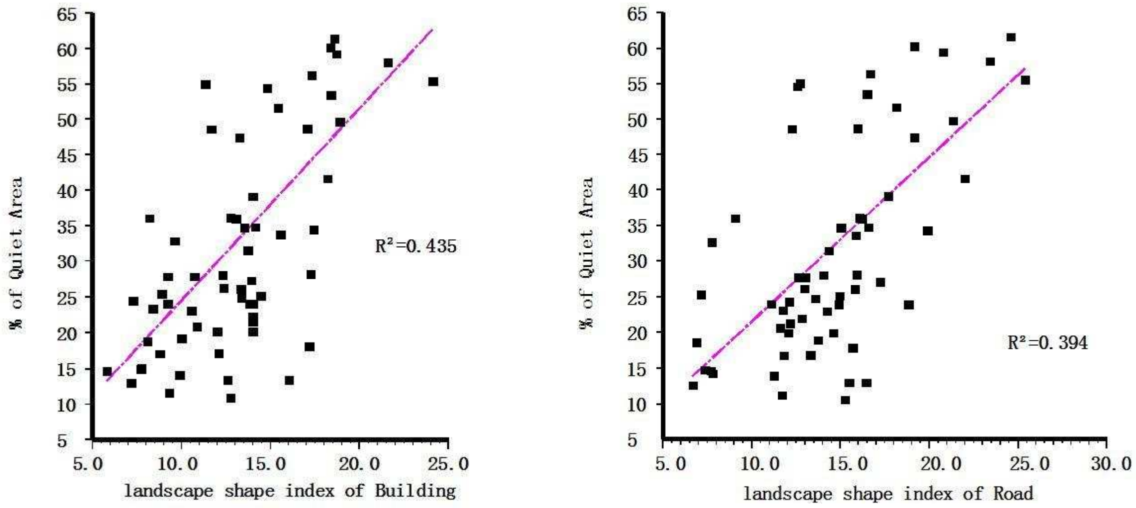


(a) **(b)**

Figure 5. The respective relationships between noisy areas in the villages and the landscape shape index of buildings (LSI_B) and the landscape shape index of roads (LSI_R) with a distance of 0 m.

3.4. Relationships between “quiet areas” in village and urban morphological parameters

The respective relationships between quiet areas in the village and LSI_B and LSI_R were examined with a distance of 300 m, where due to complicated features of the various influencing factors on sound attenuation, the variances at this distance are higher than those of 0 m, 30 m, 60 m, 100 m, and 600 m (see Fig. 6). The linear regression analysis results show that a larger LSI_B and LSI_R indicate larger quiet areas in the village; LSI_B and LSI_R can increase the quiet areas by 49% and 42%, respectively. Because the values of R^2 are both less than 0.5, a stepwise multiple regressions analysis was performed. The results show that ED was the other variable associated with “quiet areas” in addition to LSI_B, with R^2=0.518. LSI_B is the most effective variable (0.680), followed by ED (-0.288). However, due to the differences between urban and rural environments, the canyon effect hardly plays any role in noise attenuation in villages with low-rise buildings all around. The two parameters related to screening of buildings and geometrical divergence significantly reduce the traffic noise. The percentage of the "quiet area" increases with increasing building complexity (LSI_B), and a lower ED means a smaller total length of all building patches. Assuming that all families in a village remain equal, having some buildings connected as a row or as varied group forms may improve the barrier effect of buildings and lower the effect of diffraction. LSI_R and RAF were the other two explanatory variables for "quiet areas", with R^2= 0.523. The most effective variable was the landscape shape index of the road (LSI_R, 0.777), and the other was the RAF (-0.389). It is important to note that RLF has little influence on the traffic noise level under any conditions of varying distance between the site and the motorway (see Section 3.3); therefore, the reason for this finding could be the increased complexity and the smaller road width of the system causing less sound propagation through the streets along the roads.



（a） （b）

Figure 6. The respective relationships between the quiet areas in the villages and the landscape shape index of buildings (LSI_B) and the landscape shape index of roads (LSI_R) with a distance of 300 m.

3.5 Relationships between spatial traffic noise levels in the village and urban morphological parameters

To investigate how the spatial traffic noise levels in villages are related to urban morphological parameters, as shown in Table 5, a correlation analysis was conducted between six urban morphological parameters (see Section 2.2) and two spatial traffic noise levels, L_{10} and L_{80}, which were selected as the most sensitive indices with the highest variances caused by urban morphology. By convention, L_{10}, L_{50}, and L_{90} are used to give approximate indications of the intrusive, median, and background sound levels, respectively (Kang, 2007). However, the focus of this study is the entire process of spatial sound attenuation in the context of different urban morphologies of villages. Accordingly, sets of indices that represent the entire attenuation process are investigated to explore the most sensitive indices with the highest variances caused by urban morphology. As shown in Fig. 7, when the distance is less than 100 m, among the 60 sites, the maximum difference in noise occurs at L_{10}, which varies by more than 12 dBA with the mean of the difference between the maximum and minimum values. When the distance is 100–1000 m, the maximum difference in noise occurs at L_{80}, which varies by more than 6 dBA with the mean of the difference between the maximum and minimum values. Therefore, these results indicate that L_{10} (0–100 m) and L_{80} (100–1000 m) can be used and that each are more sensitive to urban morphology than are the other indices.

Table 5. Correlations between spatial traffic noise levels in the villages and the urban morphological parameters (2-tailed). Significant correlations are marked with * ($p<0.05$) and ** ($p<0.01$).

Distance(m)	**Indices (dBA)**	**Urban Morphological Parameters**					
		CAR	**LSI_B**	**PD**	**RLF**	**RIF**	**LSI_R**
0	**L10**	**.287****	**-.635****	.250	.218	.165	**-.566****
30	**L10**	.238	**-.622****	.217	.198	.146	**-.558****
60	**L10**	.225	**-.632****	.206	.181	.133	**-.571****
100	**L10**	.211	**-.631****	.190	.148	.125	**-.580****
300	**L80**	-.022	**-.694****	.065	.131	.010	**-.617****
600	**L80**	-.042	**-.651****	.065	.120	-.027	**-.557****
1000	**L80**	-.026	**-.610****	.091	.124	-.014	**-.522****

It can be seen in Table 5 that LSI_B and LSI_R have significant negative correlations with L_{10} for distances less than 100 m ($R_s>0.5$, $p<0.01$); these parameters also have significant negative correlations with L_{80} for distances of 300–1000 m ($R_s>0.5$, $p<0.01$), which suggests that greater building and road complexity create less noisy outdoor spaces in terms of L_{10} and L_{80}. It is important to note that while CAR has a positive relationship with L_{10} at 0 m ($p<0.05$), PD, RLF, and RIF have no correlation with any of the indices at seven distances. These findings suggest that the number of building patches and road intersections and the total road length do not necessarily affect L_{10} and L_{80}.

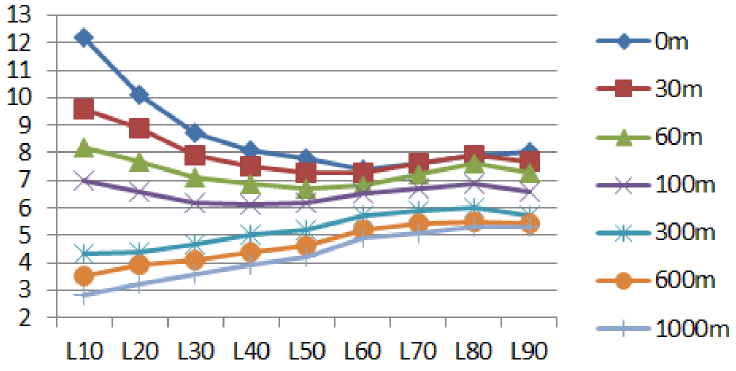
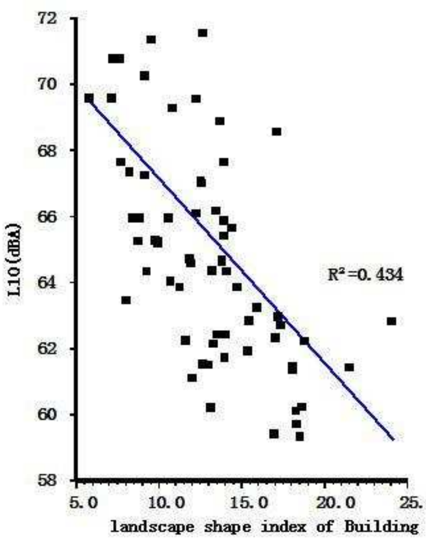
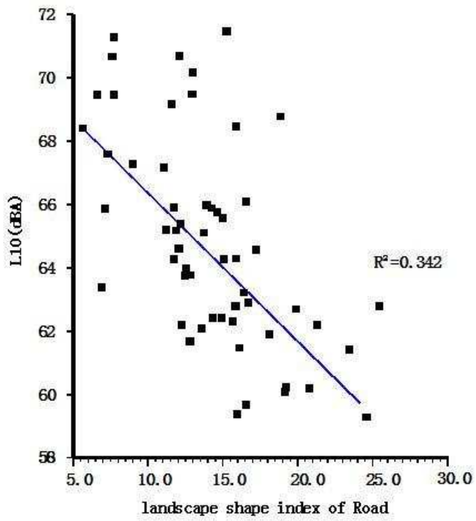


Figure 7. Spatial noise level indices of the 60 sites with the mean difference of the maximum minus the minimum values shown for each index. The different coloured lines represent distances between the site and the motorway of 0 m, 30 m, 60 m, 100 m, 300 m, 600 m, and 1000 m.



(a)

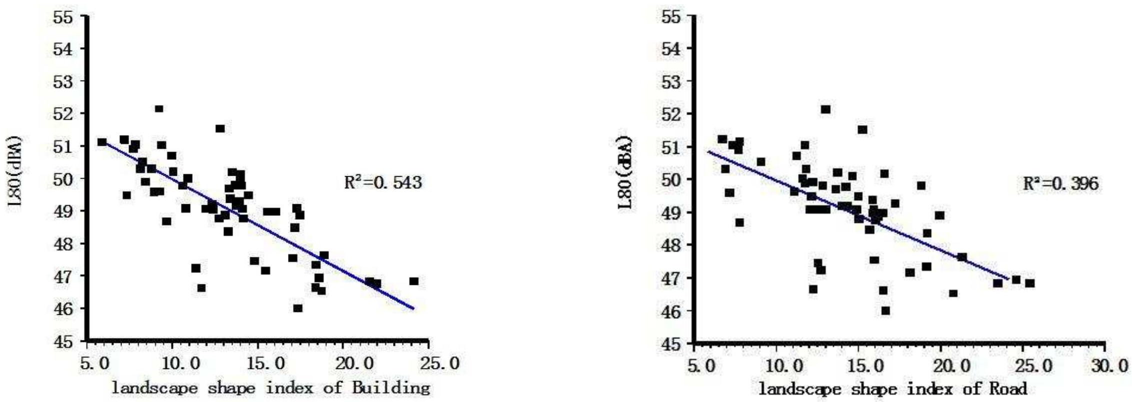


(b)

Figure 8. The respective relationships between the spatial noise level indices L_{10} in the villages and the landscape shape index of buildings (LSI_B) and the landscape shape index of roads (LSI_R) with a distance of 0 m.

Fig. 8a and b further show that increasing LSI_B and LSI_R decreases the noise of villages by 10 dBA and 8.5 dBA at 0 m, respectively. Because the values of R^2 are both less than 0.5, a stepwise multiple regressions analysis was performed. The results show that CAR was the other variable associated with L_{10} in addition to LSI_B, with R^2=0.568. The most effective variable was the landscape shape index of the building (LSI_B, -0.671), followed by CAR (0.427). Therefore, the results suggest that greater total building coverage, ground surface area and façade area would improve sound absorption, improve the barrier effect of buildings, and lower the effect of diffraction. LSI_R, RAF, and BSAPAR were the other three explanatory variables for L_{10}, with R^2= 0.554. The most effective variable was the landscape shape index of the road (LSI_R, -0.691), and the other two were RAF (0.441), for a reason similar to the "noisy areas" (see Section 3.3), and BSAPAR (0.267), for a reason similar to CAR in this section. These findings suggest that a site with more complexity, smaller road widths, and with either less total building coverage or ground surface area would result in a quieter environment in terms of L_{10}.

The relationships between L_{80} and the dependent morphological parameters were examined with a distance of 300 m because the variances at this distance are higher than those of 0 m, 30 m, 60 m, 100 m, and 600 m. Fig. 9 further illustrates that L_{80} may decrease by 9.2 dBA and 4 dBA with increasing LSI_B and LSI_R, respectively. Therefore, controlling the value of LSI_B is a very effective method to reduce the background noise of the village, possibly because the sound propagation through the road is much less than the barrier effect of the buildings and village layout. In Fig 9 b, the results of stepwise multiple regressions show that LSI_R and RAF are the other two variables related to L_{80}, with R^2= 0.520. The most effective variable was the landscape shape index of the road (LSI_R, -0.768), followed by RAF (0.427), for reasons similar to those discussed in Section 3.4.



(a) (b)

Figure 9. The respective relationships between the spatial noise level indices L_{80} in the villages and the landscape shape index of buildings (LSI_B) and the landscape shape index of roads (LSI_R) with a distance of 300 m.

4. Conclusions

In view of the seriousness of the traffic noise problem in villages located on or near well-travelled motorways in northeast China, this paper discusses how to improve the traffic noise resistance of rural residential areas through design and planning.

Increasing the distance between the village and the motorway can be effective for reducing the traffic noise, but there are tremendously different effects on traffic noise attenuation when increasing the distance to various village forms. When the distance is increased from 0 to 300 m, the largest and the smallest decreases in L_{10} vary by 6 dBA among various villages, which is different from that from 600 to 1000 m, by over 11 dBA. Comparing the seven distances, it was found that within 100 m, "noisy areas" decreased gradually, by approximately 5% for each additional 30 m of distance, and when the distance is greater than 1000 m, there are no "noisy areas" in village. Considering the present situation of the 60 sites, 55% of the sites would not meet the class-2 standard with which the acoustic environment is suitable as residential areas.

With regard to the orientation relationships, there are two types of village, isotropic and anisotropic. Anisotropic villages are more suitable for improving the traffic noise resistance of the rural residential areas by changing the orientation relationships. Most villages were anisotropic villages, for which the "noisy area" is much more affected by the orientation relationship than are L_{avg} and the "quiet area". There were alternately better and worse orientation relationships which can be found by comparing the acoustic variables among different orientation relationships, and the better regions were much fewer than the worse regions. For example, in northeast China, 30°, 120°, 135°, and 315° could be adopted to improve the acoustic environments, and 75°–90°, 255°–270°, 180°, and 345° should be avoided.

Controlling the urban morphological parameters is an efficient measure to decrease spatial traffic noise levels and enlarge quiet areas in villages. A series of urban morphological parameters was found to have significant relationships with spatial traffic noise levels ($R^2 > 0.5$) in villages of northeast China, which can be generalised as follows: "noisy area" has a negative relationship with LSI_B and two other variables regarding roads, LSI_R, and RAF; "quiet area" has a positive relationship with LSI_B and ED and is also related to LSI_R and RAF. In terms of the spatial noise level indices, LSI_B and CAR are the two variables associated with L_{10}which is also associated with LSI_R, RAF, and BSAPAR. LSI_B can more effectively reduce L_{80} than LSI_R. RAF is the other parameter combined with LSI_R that is significantly related to L_{80}.

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