24th INTERNATIONAL CONGRESS ON SOUND AND VIBRATION
23–27 July 2017, London

RESEARCH ON CHARACTERISTIC OF ANNOYANCE PERCEPTION OF LOW-FREQUENCY NOISES IN DENSELY POPULATED CITIES

Zhiyue Shao[1.2], Weichen Zhang[1.2], Yude Zhou[1.2] and Wenying Zhu[1.2]*

1.Shanghai Academy of Environmental Sciences
2.Shanghai Engineering Research Center of urban environmental noise control
email: zhuwy@saes.sh.cn

People in densely populated cities are usually exposed to many artificial low-frequency noise sources. Although the human auditory system is not so sensitive to low-frequency noises, many researches have indicated that the low-frequency noises are more annoying than the mid and high frequency noises when they are equally loud. Yet there is still no consensus on how to evaluate the low-frequency noises, especially on whether A-weighted sound pressure level is adequate for that. This research set up the database of machinery and transportation noise sources in the typical densely populated cities such as Shanghai via collecting and classifying samples of several kinds of low-frequency noise sources, including ventilation, air-conditioners, transformers, and pumps around residential area as well as vehicles, light rails, and trains. With the semantic differential (SD) method, the annoyance of these samples which were adjusted to the same A-weighted sound pressure levels was subjectively evaluated. The results of both machinery and transportation groups suggest that the more dominant the low-frequency content, the more annoying the sample. This implies that when the subjective annoyance of noises, whose low-frequency content is dominant, are evaluated, the A-weighted sound pressure level is apparently inadequate. According the subjective results, the relationship of annoyance and the ratio of low-to-mid/high frequency content was derived.

Keywords: low-frequency noise, subjective annoyance, urban environmental noise

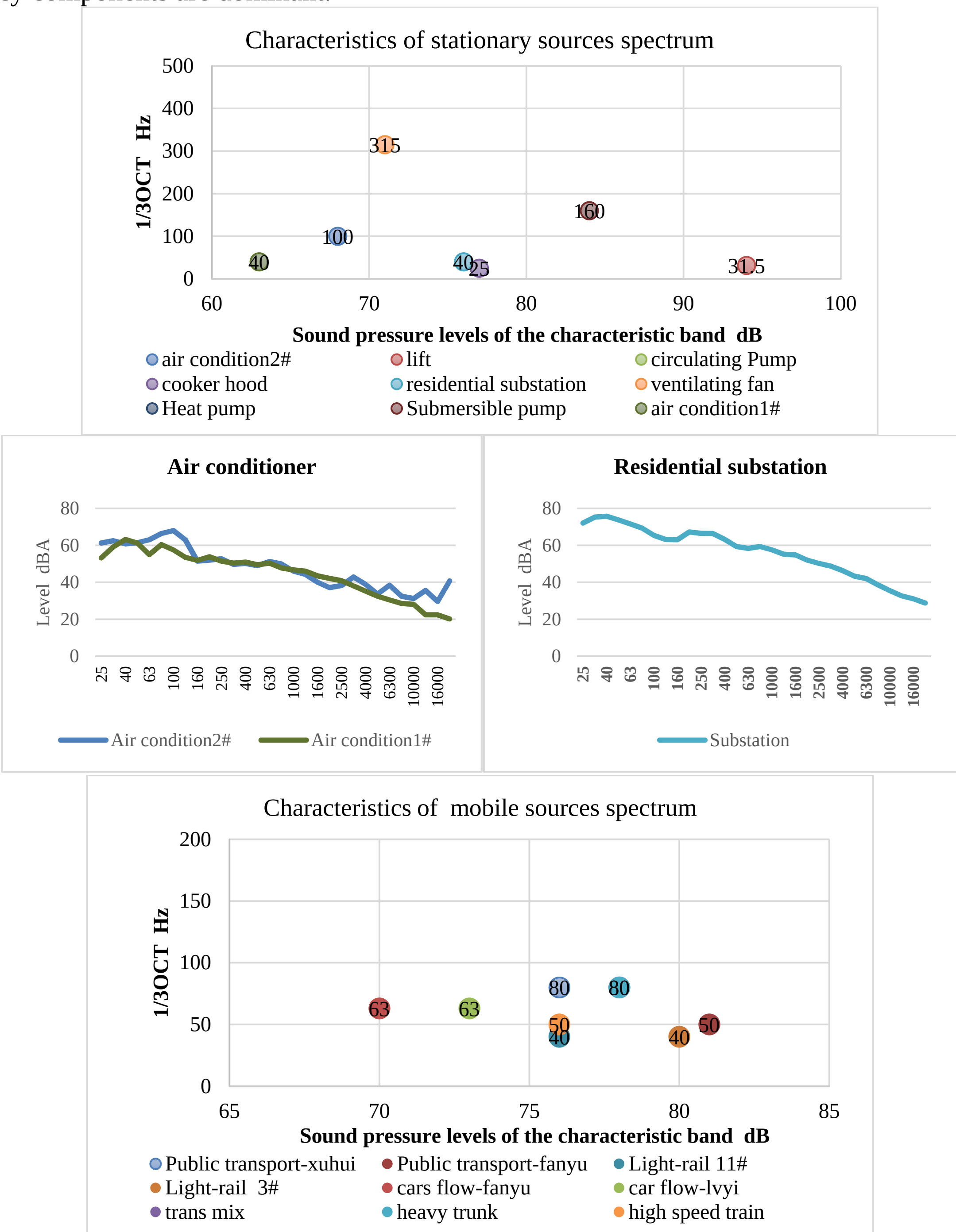
1. Introduction

Cities in China accelerate development in recent years. With cities' continuous expansion, the density of big cities increases greatly especially like Shanghai, Beijing, Guangzhou, and Shenzhen. With severer urban transportation burden and denser buildings, the traffic and equipment noises are all around in the cities. These sources contain lots of low frequency components, and the energy of low frequency noise could be hardly absorbed and attenuated, leading to a high proportion of low frequency band energy in the background noise in areas near these sources, showing the characteristic of low frequency noise pollution. Although human auditory system is not so sensitive to the low frequency noise at low sound pressure levels, the low frequency noise is more annoying at equal A weighted sound pressure level. Exposed to the low frequency noise for long periods could cause cardiovascular disease, disturb sleep and cognitive ability [1], etc. Thus, the low frequency noise problem in densely populated cities could not be ignored. Yet it is believed that A weighted sound pressure level underestimate the annoyance caused by low frequency noise [2], researches on indicators of effectively evaluating low frequency noise should be put on the agenda.

2. Analysis on the current situation of low frequency noise pollution

2.1 High proportion of low frequency band energy (20~315 Hz)

Densely populated cities contain various noise sources, the spatial distributions of which are very wide. There are stationary and mobile sources classified by mobility. In the residential areas along the traffic trunk, stationary and mobile sources both contribute low frequency noises to the environment, which could reflect among the buildings for several times, resulting in the accumulation of low frequency energy. Figure 1 indicates the spectral characteristic of these sources, in which the low frequency components are dominant.



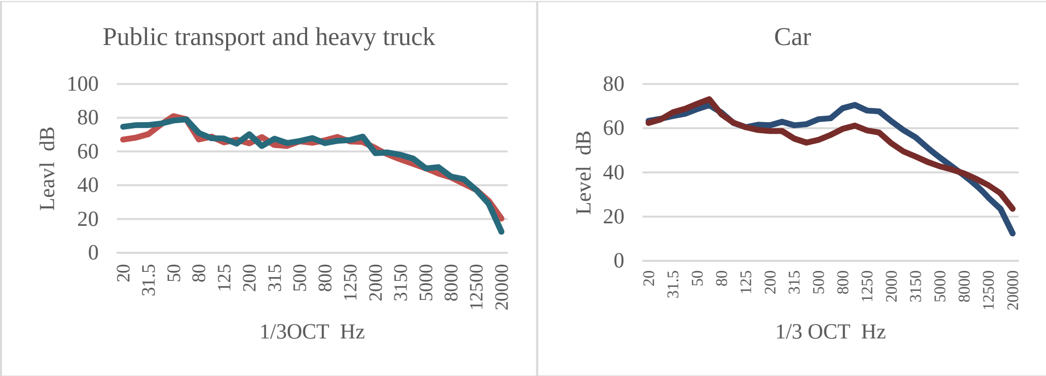


Figure 1 Characteristics spectrum of typical urban low frequency noise sources

The characteristic frequencies of more than three-quarters of stationary sources, like air-conditioners, pumps, and substations, are lower than 315 Hz, the highest level of which could be 90 dB; in traffic sources, noises of trucks and buses contains lots of low frequency components, and the level below 80 Hz could be over 80 dB, and the characteristic frequencies of light rails are between 40 to 80 Hz.

2.2 The formation of low frequency background noise

Figure 2 shows the attenuation characteristic of low frequency noise on the side of traffic trunk. The decrease of A weighted level with distance is obvious, yet the energy of frequency bands below 315 Hz hardly decay with levels ranging from 65 to 70 dB, and with high frequency energy attenuated, the proportion of low frequency energy increases to 99%. Thus, without masking of the high frequency components, the low frequency noises produce muffled hum, and some low-frequency sensitive people would be greatly disturbed [3].

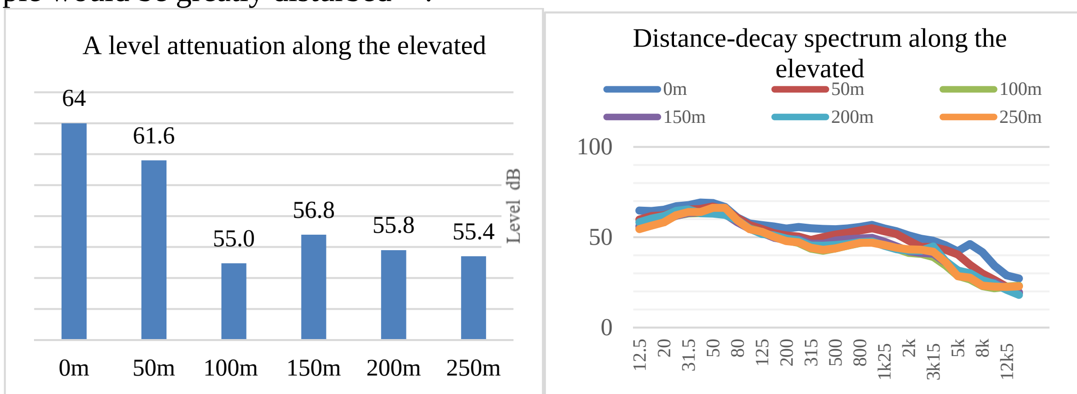


Figure 2 Typical attenuation of low-frequency sound in distance

2.3 Indicators effectively assessing the low frequency noises needed

A weighted sound pressure level is widely used to evaluate the environmental noise all over the world, which could well reflect human's perception of the intensity of sounds. However, as the problem of annoying low frequency noises arises, researchers think that the annoyance from low frequency noises is underestimated using A weighted level to evaluate them [4-6]. In an annoyance assessment test, subjects evaluated samples collected in the residential areas along the traffic trunk. The results showed that when the A weighted level was more than 56 dB(A), over 50% of people felt highly annoyed (Figure 3). Yet the limit for environmental noise in this kind of area is 60 dB(A) in daytime. It is easy to see that there is a difference of 4 dB(A) caused by the underestimation of annoyance from low frequency noises.

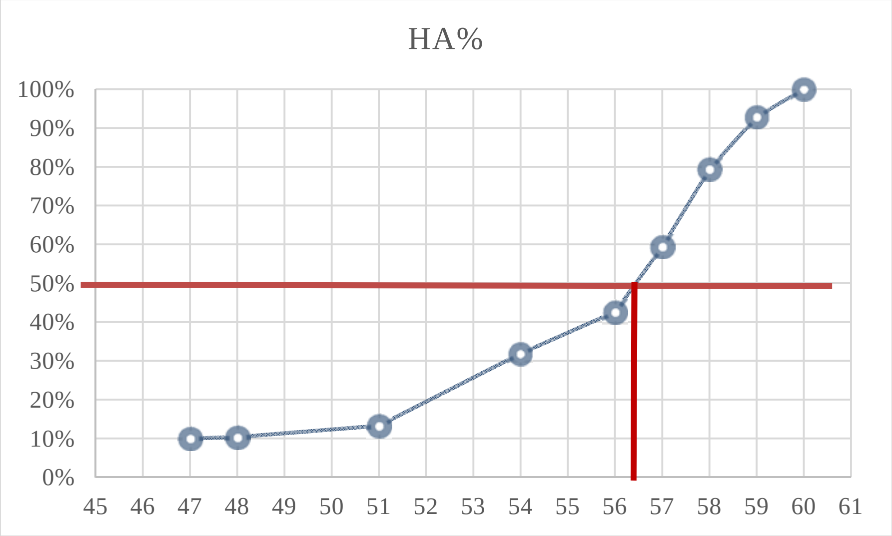


Figure 3 High annoyance curve of residential areas along traffic trunk in Shanghai

Based on the analysis of the current situation of the low frequency noise sources and results of subjective test, the problem of human's annoyance caused by low frequency noises in densely populated cities should be given attention, and the research of people's subjective perception on noises is helpful to find the indicator which could effectively assess the low frequency noises.

3. Subjective test of annoyance of low frequency noises

The collected samples of low frequency noise sources were used in laboratory tests (Figure 4). The tests contain two parts. In both subjective tests, 7-scale was adopted in the test method. In the first part, the A weighted level of the stationary sources was adjusted to 60 dB(A) and that of mobile sources was adjusted to 70 dB(A). The A weighted level was controlled to observe the effect of other parameters on the annoyance, and the relationship of annoyance and parameters would be analysed to obtain reasonable indicator.

In the second part, the indicator obtained which could effectively assess the low frequency noise was researched in detail. Several samples of typical sources were chosen to adjust the spectrum by filters with A weighted level kept unchanged, obtaining four level differences (using D to denote) between the low (20~315 Hz) and mid/high (0.4~20 kHz) frequency bands, which are 0, 10, 20, 30 dB (Figure 5). This test aims to obtain the relationship of annoyance and D. 27 volunteers with normal hearing were recruited. Anchored semantic differential method was adopted, and the anchor stimulus was the corresponding sample whose spectra was not adjusted. The subject finished all judgements in 20 minutes.

Figure 4 Subjective tests in Semi-anechoic chamber

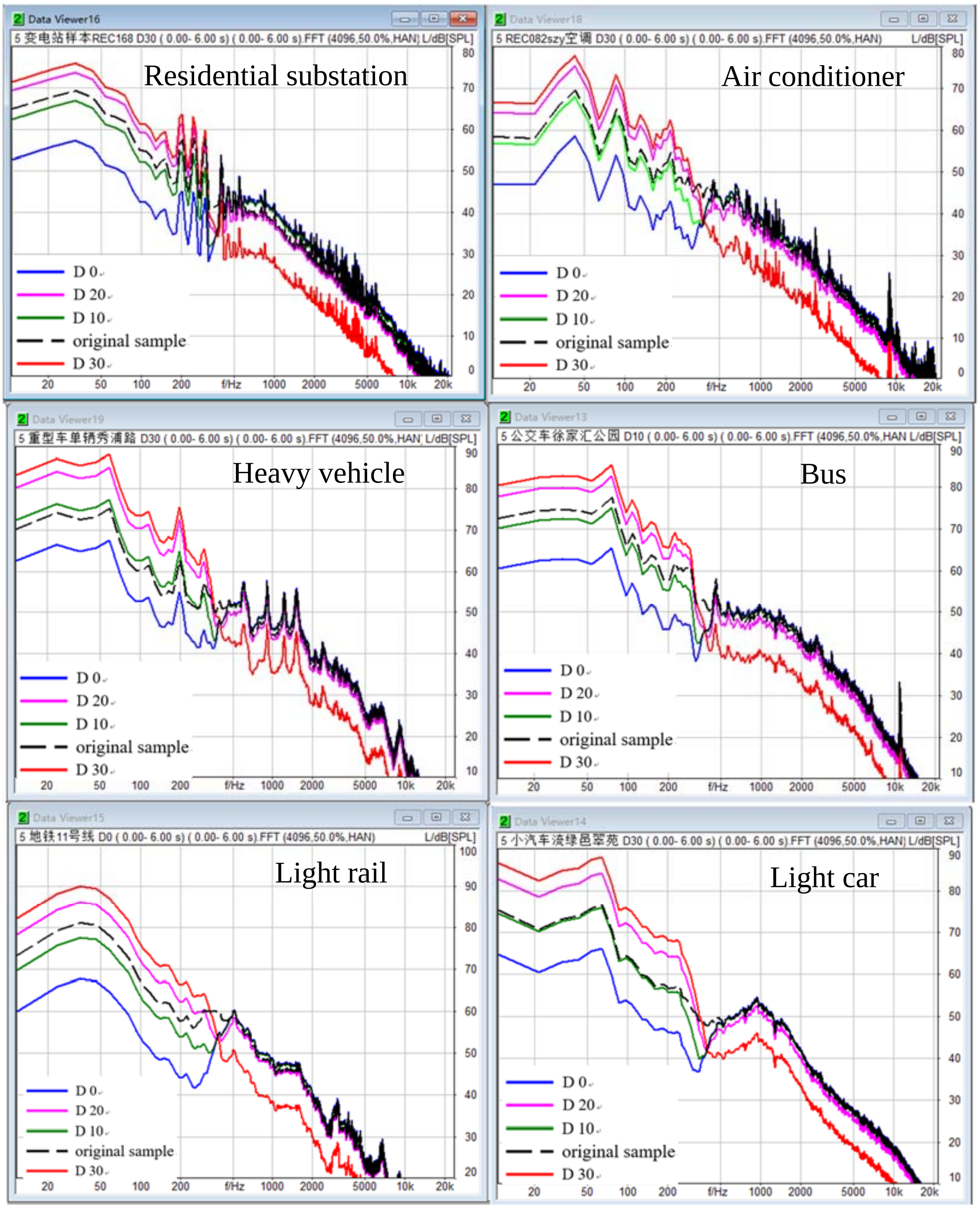


Figure 5 Spectrum of adjusted low frequency signals in the second test

4. The evaluation indicator of low frequency noise

Through the subjective tests, the relationships of acoustic parameters and annoyance were analysed. Given that the A weighted level was set constant, the most relevant parameter to annoyance could be found.

4.1 The spatial distribution of annoyance from low frequency noises

The first test ranked the annoyance from different sources (Figure 6). The results showed that the pumps, air conditioners, and transformers were the main stationary sources of low frequency noise in the residential areas, and the buses, trucks, and light rails were the main mobile sources. Thus, the ratio of heavy vehicle is a key factor affecting the annoyance of people in the residential areas along the traffic trunk. In addition, the traffic control in Shanghai makes heavy vehicles driving outside the outer ring, so the annoyance of samples collected in the suburb was obviously higher (Figure 7).

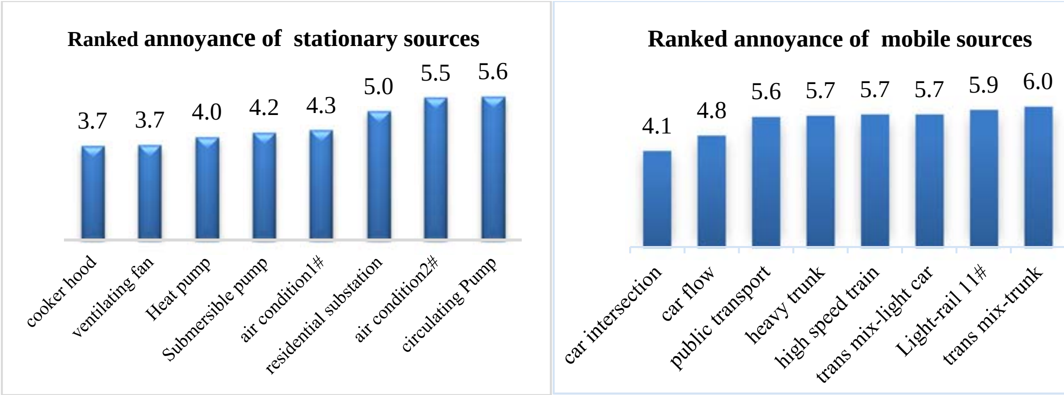


Figure 6 Ranked annoyance of low frequency sound sources

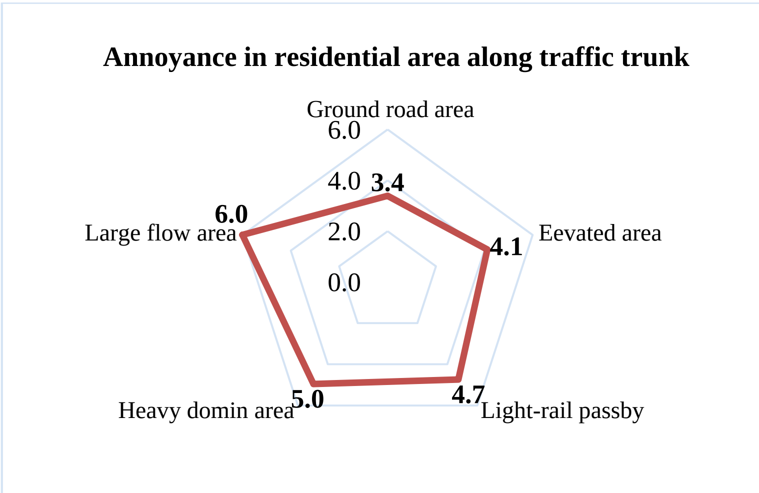


Figure 7 Annoyance in various types of residential environment

4.2 Screening evaluation indicator of low frequency noise

Several parameters of the samples used in subjective tests were calculated, including D, difference of L_C and L_A, the level of low frequency band (20~315 Hz), loudness, sharpness, and linear scale sound level. The determination coefficient of annoyance and each parameter was calculated. The results showed that considering both stationary and mobile sources, D was the best indicator relevant to the annoyance (Table 1 and Figure 8).

Table 1: Comparison of determination coefficients of acoustic and psychological parameters

Determination coefficient	R^2	
Category	Stationary	Mobile
LF-MHF(boundary: 315Hz)	**0.86**	**0.86**
C-A	0.86	0.80
LF(<315 Hz)	0.85	0.73
Loudness	0.79	0.91
Sharpness	0.38	0.07
Liner scale	0.85	0.80

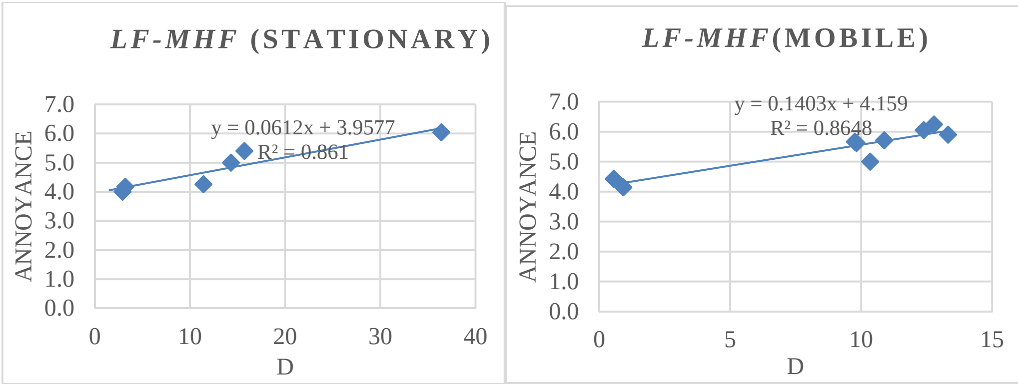


Figure 8 Relationship of annoyance and D

The second test was designed to research the relationship of annoyance and D in detail. The results showed that the increasing speed of annoyance with D was higher for mobile sources than that for stationary sources (Figure 9).

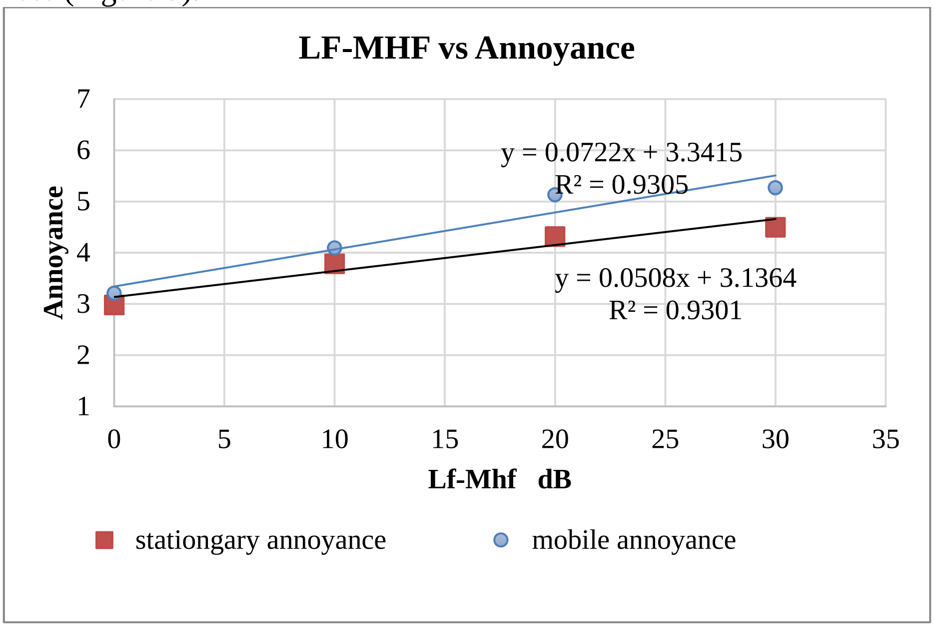


Figure 9 Annoyance changing trends with D

5. Summary

There is no doubt that the current noise control technology could reduce the energy of the whole frequency bands, yet it is still inadequate at low frequency, and as the high frequency components are absorbed in the process of propagation, the low frequency components are especially prominent. There is a group of people who are more sensitive to the low frequency noises, so they are easier to get annoyed by these sounds. This caused lots of complaints to the urban sound environment. As the expansion of big cities, this problem will be more severe.

As A weighted level underestimates the annoyance from low frequency noise, there is a problem that the noise level is lower than the limit of sound environment, yet lots of people still feel annoyed. Thus, the annoyance caused by the low frequency noises should be considered to amend the limits of sound environment quality.

This research proposes the indicator D highly relevant to the annoyance. It also provides a new idea about reducing the annoyance from low frequency noises, which is making D smaller. The traditional control measures are reducing the energy of low frequency bands, yet from the perspective of masking, mid/high frequency components could be added to reduce D, which has already been used in soundscape research.

ACKNOWLEDGMENTS

This work was supported by grants from the Environmental Protection Scientific Research Funds of Shanghai ([2015] No.26). The authors express gratitude to all the researchers and participants involved in the work.

REFERENCES

1 WHO. *Noise. Environmental health criteria document*，Geneva, Switzerland, (1980).

2 Di Guoqing, *Low Frequency Noise.* Zhejiang University Press, (2013).

3 Leventhall G. Low Frequency Noise. What we know, what we do not know, and what we would like to know. *Journal of Low Frequency Noise, Vibration and Active Control*, **28**(2):79-104, (2009)

4 Broner N. *Low frequency noise annoyance*. PhD Chelsea College, University of London, (1979).

5 Kjellberg A, Tesarz M, Holberg K, Landstrom U. Evalation of frequency-weighted sound level measurements for prediction of low-frequency noise annoyance. *Environment International*, **23**(4):519-527, (1997).

6 Cocchi A, Fausti P, Piva S. Experimental characteristics of the low frequency noise annoyance arising from industrial plants. *Journal of Low Frequency Noise and Vibration*, **11**:124-132, (1992).