CHARACTERIZATION OF SHORT DURATION NOISE EVENTS FOR THE EVALUATION OF ANNOYANCE IN SCHOOLS EXPOSED TO TRAFFIC NOISE

Giovanni Brambilla

CNR-Institute of Acoustics and Sensors "O.M. Corbino", Rome, Italy
email: giovanni.brambilla@idasc.cnr.it

David Casini

Regional Agency for the Environmental Protection of Tuscany, Florence, Italy
email: d.casini@arpat.toscana.it

Simone Secchi and Gianfranco Cellai

Department of Industrial Engineering, University of Florence, Italy
email: simone.secchi@unifi.it, gianfranco.cellai@unifi.it,

The relationship between traffic noise and corresponding annoyance has been widely investigated in literature. In particular, the effect of noise on students has been studied, for instance the correlation between road traffic noise perceived in classrooms and the student's performance, including reduced memory, motivation and reading ability. These studies mainly investigated the relationship between the A weighted equivalent sound pressure level L_{Aeq}, measured over the teaching period and/or in noise neighborhood, and the cognitive impairment of students and children. Anyway, the annoyance of students and other subjects is frequently related to the effect of short duration noise events characterized by high levels, such as the aircraft fly-over noise, pass-by of buses, heavy trucks, motorcycles or street sweepers. These noise events are often described, over specific measurement periods, in terms of maximum A weighted SPL, L_{Amax}, or statistical levels, such as L_{A1} or L_{A10}. This aspect is not considered in the noise maps drawn in accordance with the European Environmental Noise Directive, as they provide the L_{Aeq} only, determined over day, evening and night periods. The paper analyses the correlation between the equivalent L_{Aeq}, determined over 1 hour periods, and the maximum and statistical levels due to traffic noise in different kinds of road. This analysis is carried out on several urban roads belonging to different typologies and characterized by different kind of traffic. The results can be useful for further analysis on the relationship between traffic noise events of short duration and the corresponding annoyance in schools and in other type of buildings.

Keywords: traffic noise, maximum Sound Pressure Level, statistical levels, European Environmental Noise Directive

1. Introduction

It is well known that children's learning and memory are negatively affected by noise exposure.

The cognitive impairment may affect three types of cognitive aspects: visual search (attention), intentional and incidental memory for reading tests.

Researchers are currently trying to establish how chronic noise exposure in children affects the studied cognitive processes.

In the World Health Organisation's 2011 report [1] (chapter 3, "Environmental noise and cognitive impairment in children"), the noise related cognitive impairment is defined as the "reduction in cognitive ability in school-age children that occurs while the noise exposure persists and will persist for some time after the cessation of the noise exposure".

The evaluation of the noise effects on cognition can be projected unto a dose-effect curve where the main noise descriptors, such as L_{Aeq} (or L_{dn}), maximum L_{Amax} or statistical levels (L_{A1} or L_{A10}) are related to each other.

Lercher et al. [2] studied the reaction to noise in a group of primary schoolchildren selected from a large, representative sample of children living in the lower Inn Valley of Tyrol, Austria. The noise sources were rail and road traffic and one half of the sample lived in quiet neighbourhoods ($L_{A1} = 57$ dB(A) and $L_{dn} = 46$ dB(A)), while the remaining half lived in high noise areas ($L_{A1} = 74$ dB(A) and $L_{dn} = 62$ dB(A)). The most important conclusion was that even relatively modest-level exposures to noise may have detrimental effects on the cognitive systems of young children. Thus, the sound events characterized by short duration high levels may be important such as the exposure to medium or elevated L_{Aeq} levels at school and out of school environment.

Other studies showed that the reaction of students to environmental noise varies as a function of their age.

Hygge et al [3, 4] found that the strongest effects of noise for recall and recognition of the text were for children aged 13-14 years. In particular, about 10% of the children had a cognitive reduction with L_{Aeq} level equal to 42.5 dB(A), and further, language based abilities, such as reading, understanding and recalling, were the most vulnerable of the noise sensitive cognitive functions.

In another study, carried out on a sample of 142 primary schools in central London, Dockrell and Shield [5, 6] found that the children's levels of annoyance were related to the maximum noise levels recorded outside the schools. Moreover, there was a hierarchy of sounds that was found to be annoying, since trains, motorbikes, trucks and sirens were rated as the most annoying, while trees were rated as the least annoying. They also found that younger children of primary schools are more affected by ambient and background levels of external noise, while the performance of older children of the same schools is more closely related to maximum noise levels. This suggested that the performance of older children (11 years old) is affected by the noise of individual events such as sirens, lorries or motorbikes passing the schools. They studied the correlations between outdoor L_{Aeq}, L_{Amax}, and L_{A90} levels with the score obtained by children in aptitude tests.

Outdoor noise levels are related to indoor noise through the façade sound insulation and the internal reverberation time as described by the standard ISO 12354-3 [7].

In many countries, acoustic performances of school façades are very strict to guarantee a comfortable acoustic indoor environment. An overview of the limit values for acoustic performances of school façades in some European and South America countries is given in [8].

In Italy, acoustic requirements for school facades are very high and are described by the national decree of December 1997 [9] and by the national standard UNI 11367 [10, 11]. From previous studies of authors [12, 13], it is evident that façade acoustic performances of typical Italian schools are significantly lower than the limit values set by Italian laws. Anyway, when considering the outdoor traffic noise in terms of equivalent level, the intrusion of noise from outside seems to be not problematic, since indoor levels due to traffic noise is usually below the limit values. On the other hand, maximum sound levels due to short duration outdoor noise events may interfere with teacher speech, especially at lower frequencies.

Therefore, it does not seem appropriate to set the limit values only in terms of indoor equivalent Sound Pressure Level as in the case of many national or WHO [14] regulations. Instead, attention should be focused to the short duration noise events and, therefore, to their maximum SPL that could largely exceed the equivalent SPL.

Unfortunately, it is very difficult to give specific indications for the amplitude of these events, since the maximum SPL due to a vehicle pass-by depends not only on its distance from the façade but also on its speed, the way of driving, the kind of road surface and other parameters.

Some studies and guidelines [15, 16, 17] propose to assess the noise impact of new roads, evaluating the percentage of measuring intervals, each lasting 15 min or 1 h, for which it is L_{AFmax}(interval) - L_{Aeq}(interval) > 15 dB, in the night period.

Another work [18] shows that maximum levels due to vehicle pass-by (L_{AFmax}) have a very broadened frequency distribution, for each vehicle class (passenger cars, non-articulated trucks, articulated trucks, motorcycles). In particular, the standard deviation has its minimum value for cars passing at 80 km/h (3.5 dB) and the maximum one for articulated trucks travelling at 100 km/h (9.0 dB) with a significant overlapping of the distributions of each vehicle class.

The aim of this study is to analyse the typical distribution of noisy events due to traffic noise in daytime, as a contribution to study their effect on corresponding annoyance at school.

2. Material and Methods

The Sound Pressure Levels SPLs continuously monitored in 32 urban roads in four Italian cities, located in Tuscany and Lombardy regions, have been examined. The dataset included roads in various urban contexts and with different traffic flows, both leading to a range of daytime (06-20 hours) equivalent level L_{Aeq} from about 57 to 75 dB(A).

For each street, measurements were carried out at fixed distances from the carriageway and at the height of about 4-6 meters from the pavement in order to minimize the effect of specific local noise such as chatter, closures of car doors and others. The duration of each measurement was at least 24 hours excluding weekends and holidays.

Some statistic acoustic parameters were acquired for each street but, for the purpose of this study, only the A weighted maximum level, L_{Amax}, and the statistical level L_{A1} were considered. Indeed, these two parameters are of interest for the analysis of acoustic annoyance in schools and also in other type of environments. For instance, L_{Amax} was used in some studies to analyse the effect on children performances at school. Shield and Dockrell [19] found that L_{Amax} showed the highest correlation with the school performance (measured as standardised assessment test scores) of children aged 7 and 11. However, as L_{Amax} represents the SPL of a single noise event occurred once during the measurement interval, it may be unappropriated to correlate the descriptor of such event with the acoustic annoyance and the student performance.

The statistical level L_{A1} is the SPL exceeded for 1% of the measurement time. With reference to time intervals of 1 hour, L_{A1} is the SPL exceeded for a total duration of 36 seconds and, therefore, it may be more properly associated with the acoustic annoyance than L_{Amax}.

All the L_{Aeq}, L_{Amax} and L_{A1} data were analysed with reference to time intervals of 1 hour. Indeed, this time interval is the basic module for the organization of lesson time schedule. Moreover, the typical duration of road traffic noise measurements is 1 hour. Anyway, the choice of the time interval length can influence the value of acoustic parameters.

Figure 1 shows, as an example, the linear regression between L_{Amax} (left) and L_{A1} (right) and L_{Aeq} measured in a single street at different time intervals (1 hour, 10 minutes and 1 minute). L_{A1} is slightly influenced by the time interval length, especially for L_{Aeq} values above 60 dB(A), while L_{Amax} is strongly influenced by the time interval length and shows greater values when the time interval is longest (1 hour).

For each street, the linear regressions have been analysed with reference to the day-time period as defined in Italy, from 06 to 20 hours [20], after the implementation of the European Environmental Noise Directive [21].

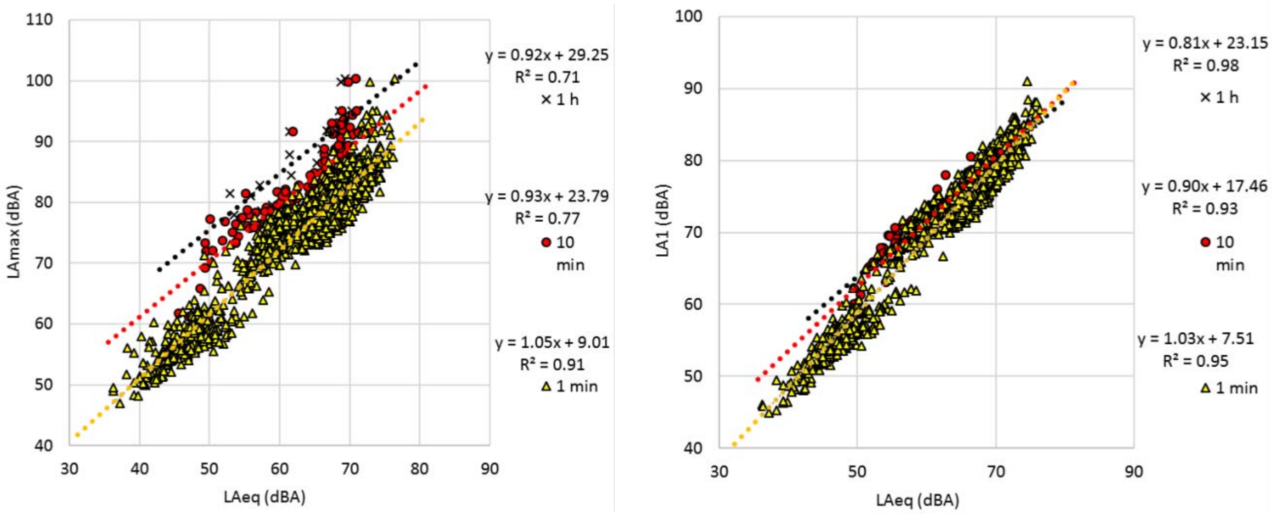

Figure 1 – Linear regression between L_{Amax} and L_{Aeq} (left) and L_{A1} and L_{Aeq} (right) measured in a street at different time intervals (1 hour, 10 minutes and 1 minute).

3. Results and discussion

Figure 2 shows the results of the linear regressions between the hourly L_{Aeqh} versus the corresponding values of L_{Amax} and L_{A1}, for the 32 streets analysed.

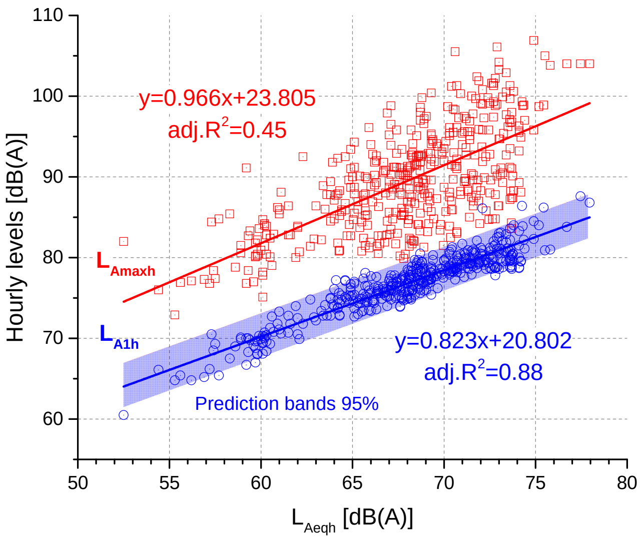

Figure 2 – Linear regressions between hourly values of L_{Amax}, L_{A1} and L_{Aeq} for all the streets.

The correlation for L_{A1} is very good, while L_{Amax} shows a greater dispersion of data. Indeed, L_{Amax} measured in a time interval of 1 hour may be influenced by exceptional events, such as particularly noisy vehicles or sirens. However, these events are typically present in traffic noise and it would be inappropriate to exclude them from the analysis. The difference between the slopes of L_{Amax} and L_{A1} is statistically significant at 95% level of confidence (p-value = 0.004).

Figure 3 shows the distribution of L_{A1} fitted – observed values in bins of 1 dB width and the corresponding normal curve. The histogram is rather symmetric and the bin centred at 0 dB shows the highest value of occurrences (31%).

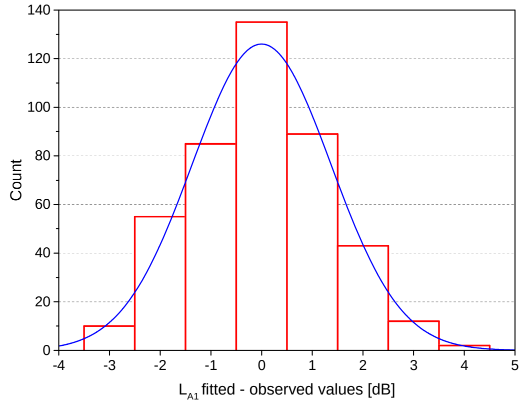

Figure 3 – Distribution of L_{A1} fitted – observed values in bins of 1 dB width and the corresponding normal curve.

Figures 4 shows the scatter plot of the medians of the differences (L_{Amax} - L_{Aeq}) versus L_{Aeq} (red square symbols) and of the medians of the differences (L_{A1} - L_{Aeq}) versus L_{Aeq} (blue circle symbols). The medians are calculated over the hourly values and L_{Aeq} is referred to the daytime period (06-20 hours), for each of the 32 streets. The correlation is rather poor, especially for L_{Amax} versus L_{Aeqd}. The average value of the differences between hourly values of L_{Amax} and L_{Aeq} is 21.5 dB, with a standard deviation of 4.7 dB, whereas the average value of the differences between hourly values of L_{A1} and L_{Aeq} is 8.8 dB, with a standard deviation of 1.6 dB. Standard deviations refer to all the analysed hourly values (448 = 32 streets × 14 hourly values).

It is interesting to point out that the L_{Aeqd} increasing corresponds to an increasing of the spread of the differences L_{Amax} – L_{Aeqh}. In addition, the regression line of L_{A1} - L_{Aeqh} versus L_{Aeqd} shows that the former parameter decreases with increasing of the latter.

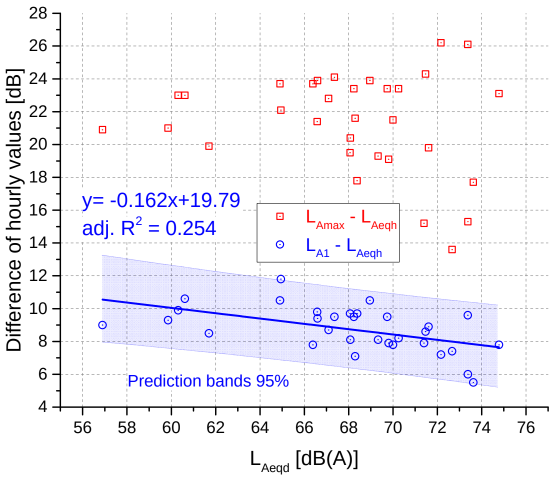

Figure 4 – Scatter plot of the medians of the differences (L_{Amax} – L_{Aeqh}) vs. L_{Aeqd} (red square symbols) and of the medians of the differences (L_{A1} – L_{Aeqh}) vs. L_{Aeqd} (blue circle symbols).

According to the European Environmental Noise Directive [21], Member states have to draw noise map for agglomerations with values of L_{den} for road traffic noise. From this value, it is possible to estimate the corresponding L_{Aeqd} (6-20 hours) with a standard deviation of the error of ± 1.9 dB by the following empirical relationship:

$$L_{Aeqd,6-20h} = 0.8881 L_{den} + 2.5364 \quad dB(A) \tag{1}$$

The relationship (1) was obtained by linear regression performed on a dataset of 1117 pair values of L_{den} and L_{Aeqd} of road traffic noise monitored continuously for 24 hours in 38 Italian towns of different sizes, in a previous study of the authors. Its application to the 32 roads gave a median error of the L_{Aeqd} estimate equal to -0.8 dB with a standard deviation of 1.3 dB. Thus, it is possible by the linear regression reported in Figure 4 to estimate the difference L_{A1} - L_{Aeqh}. In addition, for urban roads, the hourly L_{Aeqh} can be estimated by statistic 24-hours patterns of L_{Aeqh} referred to L_{Aeqd}, as those reported in [22]. It is important to point out that most often the patterns show similar trends in the hours from 8 to 17, corresponding to the opening hours of schools. For instance, by the hierarchical clustering (Ward method and euclidean distance among observations) applied to the dataset of 1117 time series of hourly L_{Aeqh} three 24-hours L_{Aeqh} patterns were obtained and the hourly values in the hours from 8 to 17 are reported in Table 1.

Table 1: Relative levels of the three 24-hours L_{Aeqh} patterns in the hours from 8 to 17.

Pattern		Hour								
		8	9	10	11	12	13	14	15	16
1	L_{Aeqh}-$L_{Aeqd,6-20}$	0.52	0.25	-0.03	-0.06	-0.24	-0.47	-0.64	-0.31	-0.18
2	L_{Aeqh}-$L_{Aeqd,6-20}$	0.69	0.13	-0.18	-0.09	0.06	-0.03	-0.32	-0.33	-0.25
3	L_{Aeqh}-$L_{Aeqd,6-20}$	0.17	0.15	-0.03	-0.11	-0.05	-0.21	-0.32	-0.27	-0.11

As an applicative example, it is here assumed an L_{den} value equal to 65 dB(A). By this value, equation (1) gives L_{Aeqd} = 60.3 dB(A) that provides L_{A1} - L_{Aeqh} = 10.0 dB by means of Figure 4. As Table 1 shows that L_{Aeqh} is almost equal to L_{Aeqd} for any street pattern, during hours of school activities, an L_{A1} estimation on school facade can be obtained by adding 10 dB to 60.3 dB(A) that is L_{A1} = 70.3 dB(A).

4. Conclusions

According to previous studies, acoustic annoyance at school and in other indoor environments is correlated to the environmental noise and to the occurrence of short duration noise events of great amplitude. These short duration noise events can be measured in terms of maximum sound levels, L_{Amax}, or by means of statistical descriptors, such as L_{A1}. Anyway, without the use of long term measurements, the values of these descriptors are not known for a specific street, since the noise maps drawn by the municipalities for the urban agglomerations show only the values of L_{den} for the road traffic noise. Therefore, with the aim of better characterizing the acoustic annoyance at school, it is important to define a correlation between the values of L_{den} and the corresponding values L_{Amax} and L_{A1}.

In the paper, the hourly values of L_{Aeqh} continuously monitored in 32 urban roads in four Italian cities have been linearly correlated with the corresponding hourly values of L_{Amax} and L_{A1}.

Moreover, based on previous works, a correlation between hourly values of L_{Aeqh}, analysed in this paper, and the day-evening-night level L_{den}, is shown.

Results point out that the correlation between L_{Aeqh} and L_{A1} is very good, while L_{Amax} shows a greater dispersion of data. Moreover, values of L_{Amax} are strongly influenced by the time interval length and shows greater values when this time interval is longer.

Results confirm, as in previous studies, that the distribution of the maximum SPLs is very dispersed and show that the average value of difference L_{Amax} - L_{Aeqh}, in the daytime period (06 – 20), is 21.4 dB, with a standard deviation of 4.7 dB, while the average value of differences L_{A1} - L_{Aeqh} is 8.8 dB, with a standard deviation of 1.6 dB.

As a consequence, we could consider that the statistical level L_{A1}, in comparison to L_{Amax}, is more suitable for the study of the correlation between acoustic annoyance and occurrence of short duration noise events.

Acknowledgements

The authors wish to thank Giovanni Zambon of the University of Milan-Bicocca (DISAT) for making available the noise monitoring data of some streets.

REFERENCES

1 World Health Organization (WHO), Burden of disease from environmental noise - Quantification of healthy life years lost in Europe (2011).

2 Lercher, P., Evans, GW, Meis, M., Ambient noise and cognitive processes among primary school children, Environment and Behaviour, 35, 725–735 (2003).

3 Hygge, S., Noise exposure and cognitive performance – Children and the elderly as possible risk groups, WHO Brussels, (2003).

4 Hygge, S., Boman, E., Enmarker, I., The effects of road traffic noise and meaningful irrelevant speech on different memory systems, Scandinavian Journal of Psychology, 44, 13-21 (2003).

5 Dockrell, J., Shield, B., Children's perceptions of their acoustic environment at school and at home, J. Acoust. Soc. Am., 115 (6) (2004).

6 Shield, B., Dockrell, J., The effects of classroom and environmental noise on children's academic performance, 9th International Congress on Noise as a Public Health Problem (ICBEN), Foxwoods, CT (2008).

7 ISO/DIS 12354-3, Building acoustics, Estimation of acoustic performance of buildings from the performance of elements - Part 3: Airborne sound insulation against outdoor sound, (2017).

8 Machimbarrena, M., Rasmussen, B., Comparison of acoustic regulations for housing and schools in selected countries in Europe and South America - A pilot study, Proceedings of the 22nd International Congress on Acoustics, Buenos Aires, (2016).

9 Decree of the President of the Council of Ministers 5 December 1997, Determinazione dei requisiti acustici passivi degli edifici (Determination of building passive acoustic requirements) (in Italian) (1997).

10 UNI 11367:2010, Building Acoustics - Acoustic Classification of Building Units - Evaluation Procedure and In Situ Measurements, UNI, Milan, Italy, (in Italian) (2010).

11 Di Bella, A., Fausti, P., Scamoni, F., Secchi, S., Italian experiences on acoustic classification of buildings, in Proceedings of 41st International Congress and Exposition on Noise Control Engineering 2012, INTER-NOISE (2012).

12 Secchi, S., Scrosati, C., Casini, D., Cellai, G., Busa, L., Scamoni, F., Typical acoustical performances of façades of Italian schools: the effect of the outdoor noise on the indoor acoustic comfort, in Proceedings of the INTER-NOISE 2016 - 45th International Congress and Exposition on Noise Control Engineering: Towards a Quieter Future, 3842-3853 (2016).

13 Casini, D., Cellai, G., Secchi, S., Fogola, J., Scamoni, F., Urban noise and required facade acoustic insulation of buildings: The case of some agglomerations in Italy. Proceedings of 22nd International Congress on Sound and Vibration, ICSV (2015).

14 World Health Organization (WHO), Guidelines for Community Noise, available: http://whqlibdoc.who.int/hq/1999/a68672.pdf (accessed 28.02.17).

15 Samuels, S.E., Parnell, J., Peak noise events occurring in road traffic noise, Proceedings of the 2004 annual conference of the Australian Acoustical Society (Acoustics 2004), Gold Coast, Australia (2004).

16 Campbell, J.A., Parnell, J., A vehicle maximum noise level study, Proceedings of the 2004 annual conference of the Australian Acoustical Society (Acoustics 2004), Gold Coast, Australia (2004).

17 RTA Environment and Community Policy Branch (developed by Campbell J.A. and Isles S.), RTA Environmental Noise Management Manual, RTA publication number RTA–Pub.01.142, Australia (2001).

18 Schreurs, E., Brown, L., Tomerini, D., Maximum pass-by noise levels from vehicles in real road traffic streams: comparison to modelled levels and measurement protocol issues, Proceedings of the 45th International Congress on Noise Control Engineering (Inter-Noise 2011), Osaka, Japan (2011).

19 Shield, B., Dockrell, J., The Effects of Noise on Children at School: A Review, Building Acoustics, Volume 10 n. 2, 97 – 116 (2003).

20 Legislative Decree n.194 19 August 2005, Attuazione della direttiva 2002/49/CE relativa alla determinazione e alla gestione del rumore ambientale (Implementation of directive 2002/49/CE relating to the assessment and management of environmental noise) (in Italian) (2005).

21 Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise - Declaration by the Commission in the Conciliation Committee on the Directive relating to the assessment and management of environmental noise (2002).

22 Brambilla, G., Gallo, V., Andamenti dei livelli L_{Aeq} orari nelle 24 ore del rumore urbano e indicazioni per il campionamento spaziale stratificato (24-hour time pattern of hourly L_{Aeq} of urban noise and indications for stratified spatial sampling) in Proceedings AIA 2010, Siracusa, Italy (in Italian) (2010).