MEASURING SOUNDSCAPE IMPROVEMENT IN URBAN QUIET AREAS.

G Memoli Imperial College London, Department of Chemical Engineering, London (UK)
G Licitra ARPAT, Environmental Protection Agency - Tuscany Region, Florence (IT)
M Cerchiai ARPAT, Environmental Protection Agency - Tuscany Region, Pisa (IT)
M Nolli ARPAT, Environmental Protection Agency - Tuscany Region, Florence (IT)
D Palazzuoli ARPAT, Environmental Protection Agency - Tuscany Region, Florence (IT)

1 INTRODUCTION

Noise has invariably accompanied people throughout the ages, but its types and the human perception of it have changed over time. Noise in large urban agglomerations is now seen as a factor that greatly impairs quality of life, similarly to air or water pollution. In accordance to the European Commission's Green Paper on future noise Policy, more than about 250 million people are exposed to A-weighted outdoor levels higher than 55 dB[1].

It is part of European Community policy to achieve a high level of health and environmental protection, and one of the objectives to be pursued is protection against noise. The European Directive 2002/49/EC on the Assessment and Management of Environmental Noise (END) was adopted to define a common approach to avoid, prevent or reduce the harmful effects due to exposure to noise. To that end, the EU Commission required the Member States to produce noise maps for the main sources of noise pollution (traffic, railways, airplanes, factories), described the indicators to be used (namely L_{den} and L_{night}) and, in later documents, suggested the methodologies to be followed and the algorithms for modelling noise emissions from the different sources. The work of the EU commission has been integrated by the research produced by WG-AEN, WG-HSEA and in the context of relevant EU-funded projects, which have pointed out the best practices to be shared among the Community.

However, the END has left to the Member States the ways to define and preserve Quiet Areas and special locations. These areas must be identified, their acoustical quality preserved and eventually specific Action Plans must be devised for them. The only indication given by the END is that the whole procedure must be focused on population, who will appear either as exposed, as subject to future action plans or as target for the dissemination of results.

There are many experiences in European Member States of Noise Mapping and Action Plans applied to Quiet Areas. There are also some general recommendations drawn by Working Groups established by European Commission to support the END[2,3]. However the definition, identification and protection of Quiet Areas in urban locations and in the countryside are still under discussion, not only with respect to acoustic criteria, but also to such items as future land use etc.

Particularly difficult, in this vision, is the design of solutions for urban parks, district green spots and natural areas, often exposed to great level of noise pollution because of their location and whose presence has proved to be very important for the well-being of people living nearby[4]. In these areas, a wide range of requirements must be met at the same time, as different users could require and expect a different level of “quietness”. The expectation of the people involved, then, appears to be of primary importance: the problem of identifying Quiet Areas resolves into the challenge of finding suitable indicators to map and design the outdoor environment from a psycho-acoustical point of view, describing the different areas of a city by their acoustical “fingerprint”, (e.g.: on the scale of perception, but using quantitative indicators). New indicators will also open the way to a new generation of noise maps, which will describe soundscapes and have a keen eye to people’s perception. Such maps would be crucial to define the goals to be achieved by noise control and action plans.

In addition to this, measures that reduce the overall noise level might be ineffective in the identified Quiet Areas, either because they are quite invasive to the landscape or because they are not technically possible. More in general, the necessary actions should be oriented to people perception more than to a mere reduction of the energy levels, so that the target will not only be to reduce the noise, but to improve the general well-being of users.

One attempt to solve the problem is to induce artificial variations in the "soundscape", so to create healthier sound environments (here and in the following, "soundscape" will be used as a concept to describe the whole acoustic sensation related to a place, either expected or experienced). The knowledge of the effects on humans of such variations in soundscapes, and how these variations are perceived and used by the residents, have been the subject of many studies in the latest years, so that a platform of knowledge is now well established[4] and ready for pilot action plans.

The interest in action plans based on the effect of "positive" soundscapes is growing across Europe and in particular in UK. Not only different projects have been funded by the Research Council (NoiseFutures, ISRIE) to promote emerging psychoacoustic research, but local authorities are acting in this direction. An example is the Mayor of London's Ambient Noise Strategy 'Sounder City', which is probably the first UK public policy document to promote not just noise reduction, but positive soundscape management[5].

The idea is to contrast the feeling of strain communicated by modern cities to visitors and inhabitants alike (i.e.: the individual appears to be unwelcome, as he/she is bombarded by unwanted noise from different sources and directions). This can be obtained using sounds which people regard as generally positive, often taken from the acoustical history of the city, to reduce negative perceptions of noise (this is probably one of the reasons why fountains have traditionally been such popular architectural features in public spaces). More ambitiously, it would be possible to design actions that, maybe at the cost of a slight increase in the noise level, directly affect the soundscape in an area, transforming the perception of its users. A way to do this would be superimposing an "artificial soundscape" to the existing polluted one, whose characteristics depend on the needs of end users.

1.1 Content of the present work

The present work wants to contribute to the above mentioned scenario, showing a possible path that starts from the definition of a new indicator and ends with the means for innovative Action Plans. A successful indicator provides help to design new areas and improve existing ones, directing technical efforts to achieve the "ideal characteristic" of the site, according to the end users' expectations. The different actions will be demonstrated referring to Giardino Sonoro, a site in Florence (Italy) where special sound compositions were emitted to contrast the noise due to a road.

2 THE CHARACTERIZATION OF THE INDICATOR

2.1 The definition of *Slope* and its calibration

The details for the calculation of the *Slope* indicator have been described extensively elsewhere[6,7], but it is worth remembering here that its numerical value represents the exponent S of a power function fitted, using a least squares method, to the power spectrum $G(f_0)$ of the L_{Aeq} time history in the interval [0.02, 0.2] Hz, so that

$$G(f_0) = A \cdot f_0^S \text{ where } G(f_0) = \hat{L}_{Aeq}(f_0) \cdot \hat{L}^*_{Aeq}(f_0) \qquad (1)$$

with $\hat{L}_{Aeq}(f_0)$ as the Fourier transform of $L_{Aeq}(t)$ and $\hat{L}^*_{Aeq}(f_0)$ as its complex conjugate.

Under the previous definitions, the obtained “frequency of occurrence” (f_0) is not related to the signal emitted every second, but to the time history of L_{Aeq} over a fixed amount of time: a peak in the spectrum evidences a repetitive event during the selected acquisition time. The exponent S, then, measures the correlation between events appearing in the time history[7]. A brief summary of the scale defined by the slope-S indicator can be found in Table 1.

Table 1. Brief summary of the meaning of the indicator, obtained from previous studies[6].

Type of sound/locations to be characterized	**Value of the indicator**
Quiet locations	Greater than -1
Music	Close to -1
White noise and MLS	Close to -2
Disturbed locations	Lower than -2

Also interesting for this work is how Slope has been calibrated: noise measurements were acquired in residential areas (21 locations in the municipality of Pisa[6] and 14 across the little town of San Giuliano Terme[7] in Italy) for a continuous period of 24 hours. Sites characterized by “extreme” soundscapes were selected at first: “disturbed” locations were chosen among the ones where an official complaint had been issued by the population to the local municipality. “Quiet” locations, instead, were selected by asking to the same people where they could experience a relaxing environment: they pointed out small villages in the suburbs and city parks, where noise is still present in some way, but it is not probably perceived as annoying. Other sites were added in a second stage, in order to test the selectivity of the procedure.

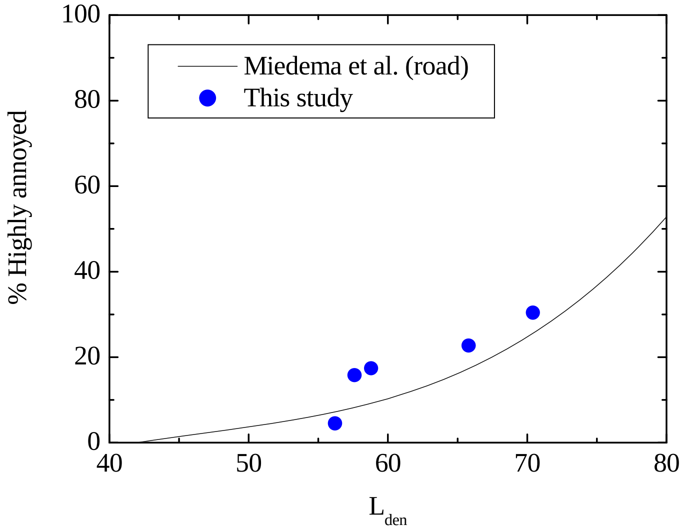
Each site was characterized by a finite set of values of *Slope*, obtained dividing the 24 hours $L_{Aeq}(t)$ in periods of 15 minutes and calculating S using eq. (1) in a selection of them (4 was found to be the minimal quantity). Hierarchical clustering was then used to group the sites out of similarity. The process distinguished the known “extreme” cases (e.g. quiet and highly annoyed locations), but also provided a numerical “distance” from the extremes for the other locations. These “mid” sites were consequently classified on a numerical scale of “predicted” annoyance.

The predictive ability of this technique was finally investigated on a selection of five “mid” sites, all characterized by traffic noise as the main source, where the long-term perception of inhabitants was assessed with interviews. The long-term annoyance assessed by questionnaires is reported in Figure 1a where the values calculated using the correlation by Miedema *et al*[8] for road traffic have been reported for comparison. Predicted and assessed annoyance matched in 4 sites over 5.

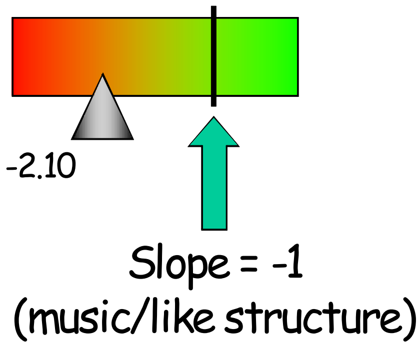
With the necessary caution due to the limited number of sites investigated, these results lead to a “numerical scale of perceived quietness”, graphically represented in Figure 1b, opening the way to action plans. The scale in figure 1b allows, in fact, an accurate characterization of existing areas, and it may give information on the dose/effect relationship for environmental noise. Such a scale may also be important for the practical design of new sites, where the “soundscape” is seen as something that can be modified to meet the expectations of the users[6].

2.2 Testing the validity of different indicators

Once found an indicator that seems to work, there is always the temptation to stick to it, without considering the more classical ones. A comparison with more classical indicators, however, is needed to understand the advantages and the limits of using the new one. *Slope* has been compared in previous studies with the “number of emergences” (defined as the number of peaks over background) and with quantities derived from statistical analysis[7], but a comparison of a more psychoacoustical nature was certainly needed.



(a)



(b)

Figure 1: Steps towards the "numerical scale of perceived quietness" using Slope: (a) classification of the "mid" sites as assessed by questionnaires, compared with the Miedema's curve estimating road traffic annoyance[8]; (b) graphical representation of the *Slope* scale, with colour representing the grade of quietness (greener for quieter) and with numbers indicating the corresponding values of *Slope*.

2.2.1 The location

The Giardino Sonoro Limonaia dell'Imperialino[9] is an urban garden in Florence facing a very high traffic road (see Figure 2). Until a few months ago, it was an open laboratory where a team of garden, sound and light architects was showing their artistic creations and sound compositions, usually in the shape of plexiglas and fabric diffusers that incorporate sound and light into a green environment. The innovative idea, developed in cooperation with ARPAT, was to use these objects as a vehicle to contrast the noise pollution due to the nearby road.

The proposed technique has something of active control methods (as it uses the noise of the source as a basis to contrast it) and something of noise masking (as the emitted sounds increase the overall background, even if only slightly) but, at the same time, it has an added value. The combined effect of the particular diffusers, their spatial distribution, the generated sounds and their order can lead to a complete distraction from the surrounding reality. Structures were optimized in previous studies[10].

The Giardino was structured in different paths, oriented to different requirements of the user (concentration, relax, listening, emphasis), each with its own structures and sounds. For the present study we used two of them:

- *Sonic Path* (Figure 2a): a path in the green where emitters were mainly built in terracotta (amphorae, ground loudspeakers, goblets) and placed on the ground, among plants;
- *Road Path* (Figure 2b,c): situated at about 8 m from the road, it was characterized mainly by a footbridge with suspended emitters in plexiglas or fabric ("dolphins") and by an area surrounded by sound emitters, where a bench for resting was available (sonic wall).

An additional microphone, mounted in the position F of Figure 2d, acted as free field reference to assess the noise of the road.

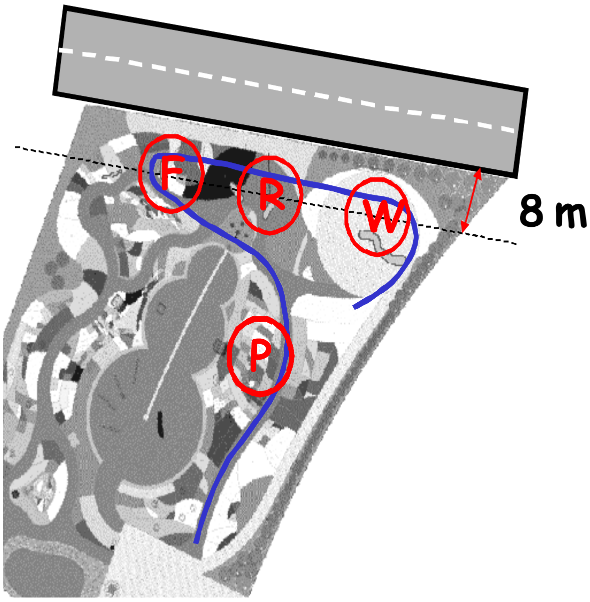
2.2.2 The measurements

Measurements were acquired using four fixed microphones (locations P, F, R, W in Figure 2d) and a binaural headset that was worn by an operator while moving along one of the paths. Two operators were involved in the procedure, in order to avoid any possible confounding effect due to height (operator A: 1.60 m; operator B: 1.80 m); no such effect was however registered.

a) Sonic path (site P and blue line in Figure 2d)

b) Sonic footbridge (site R in Figure 2d)

c) Sonic wall (site W in Figure 2d)



d) Giardino Sonoro's map and measurement locations.

Figure 2: The principal locations used for the measurements in this study (a,b,c) and their position in the general layout of the Giardino Sonoro (d).

During each acquisition one of the operators moved along one of the paths (indicated by a continuous blue line in Figure 2d), pausing for about three minutes in correspondence of the selected fixed positions, where a continuous digital recording of noise was active, and for about 1 minute in some intermediate locations, chosen for their particular significance in the park. The total time of each soundwalk was about 25 minutes. This method allowed to:

a) compare the reading in continuous with the ones of the headset, in order to check whether it is possible to describe a location through acquisitions over three minutes (this very short acquisition time should represent a "pass-by" experience, to be compared with the "long term" ones described in the previous section);
b) investigate the possibility to describe numerically the experience of a "soundwalk" and therefore to predict it.

Acquisitions were performed using the multichannel system Orchestra by 01dB, while microphones and headset were manufactured by SCS. Post-processing was performed using dB Sonic of 01dB.

2.2.3 Comparison with psychoacoustical indicators from literature

Among the classical indicators available in the literature, we have chosen some of the most "famous" ones: loudness, fluctuation strength, roughness, sharpness and unbiased annoyance[11]. The relative variation of the different indicators when the sound was switched ON is reported in Figure 3. In this figure, "+" and "-" report a minimum variation (positive and negative, respectively), while "∅" and "++" respectively a null change and a well detectable increase. Colour has also been added to Figure 3 taking into account the scale in Figure 1b: a positive change in *Slope* means a change towards "quietness" (then reported in green), while an increase of the Loudness should correspond to an increase in the expected annoyance (then reported in red). The colour yellow has been used to indicate those variations that were comparable with measurement uncertainties.

	Ref	Path	Road	Wall	Pos2	Pos4	Pos6	Pos8	Pos14	Pos15
L	∅	+	++	++	++	∅	+	++	++	++
Sh	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
FS	∅	∅	+	∅	-	+	∅	+	∅	∅
R	-	∅	-	-	∅	∅	∅	-	∅	-
UA	+	+	++	++	++	+	+	++	∅	∅
L_{Aeq}	∅	+2	+6	+8	+6	+1	+4	+7	+7	+7
SL	-12	+70	+50	+80	+20	+80	+50	+10	+30	+30
	Fixed positions				Pathway				Road path	

Figure 3: Variation of the different indicators when sound was switched ON: loudness (L); sharpness (Sh); fluctuation strength (FS); roughness (R); unbiased annoyance (UA), L_{Aeq} (change reported in dB) and Slope (SL). "Ref" position corresponds to the free field microphone. The increasing number (Pos2, Pos4, Pos6 etc.) describes the increasing distance from the start of the soundwalk (e.g. the lower point of the line in Figure 2d).

From Figure 3 it can be inferred that:

a) loudness and L_{Aeq} move towards higher values, which should correspond to an increased annoyance (as registered by the unbiased annoyance);

b) sharpness and fluctuation strength register only very slight changes and are then not good indicators for detecting soundscape changes;
c) roughness slightly decreases in almost all the cases, but its relative change is much lower than the one of *Slope*.

Roughness is then able to detect a change in the soundscape and possibly its direction, but might not be sensitive enough for design long-term applications (e.g. it might not be able to distinguish and optimize sound compositions, for instance[10]). It has, however, the advantage that, instead of *Slope*, it can be calculated in real time and it can then be used to adjust the soundscape to various changes of the source.

2.3 Assessing the change in soundscape by questionnaires

In the period 2005-2007 the team of Giardino Sonoro, lead by Lorenzo Brusci[9] realized different temporary sound installations across Europe (Koln, Paris, Madrid, Florence, Venice are a few examples) integrating sound and vegetation. Qualitative feedback from the visitors seemed to confirm the effectiveness of the technique, based in distracting the attention from the noise sources present in the neighbourhood (where one of the sources was the people itself). It was felt, however, that a specific survey was needed.

For such a survey to be effective, the interviewed were given the possibility to experience the same noise polluted area with and without the emission of sound compositions, in a site where the soundscape could be altered in a simple way (e.g. by turning a switch) and on the timescale of a soundwalk. Such a site was available in Florence where, according to the results presented in the previous section, obtained through the *Slope* indicator, an improvement was expected in the soundscape.

The following procedure, similar to the one used in determining the long-term impact of action plans, was applied during Giardino Sonoro open days in summer 2007: a specific questionnaire, based on the ones available online[11], was then distributed to all the visitors, yet respecting their willingness not to participate in the study. Visitors were briefed at the entrance of the park about the study and how to fill the questionnaire in. The latter was divided in two sequential and ordered sections:

- the first, regarding the experience with sonic installations OFF or not audible;
- the second, referring to the experience with sonic installations ON and clearly identified, both visually and acoustically.

The questionnaire included a test for self-reported sensitivity to noise, based on a scale measuring from (0) for "not at all" to (5) for "very much", where the higher scores indicate that participants are more sensitive to noise. A numerical scale (0 for "not at all" to 5 for "very much") was also used to characterize, in each part, the experience from the point of view of perceived noise (Question 1: "please describe the level of noise coming from the road nearby") and annoyance (Question 2: "how much are you annoyed by the noise coming from the road nearby?"). A free text question was also added at the end of each section to allow for any further description of the experience.

Visitors were invited to experience all the area before completing the section of the questionnaire with sound ON: no specific paths, time limits or specific location for filling the questionnaire in were suggested (one of the researchers was always at hand, ready to answer to any doubts relative to the completion of the questionnaire). When the interviewed could not experience the park with the installations OFF, he/she was suggested to move in a location where sound was not audible, just outside the garden but at about the same distance from the main source of noise (e.g. the road, with an average L_{Aeq} of 65 dBA).

A visit to the park usually lasted 20 minutes. Visitors usually paused longer at some of the locations, out of personal preference, sometimes neglecting other parts of the park. A general preference was for the areas where sitting was available (locations designed for long time relax) or for those where the sound level was higher or more particular (areas designed to surprise).

Visitors were quite collaborative and interested in the study; nevertheless, the collected questionnaires often resulted incomplete, especially in the part relative to the case with sound OFF. It is reasonable to think that this happened because the necessity of completing both section was not sufficiently stressed, in order not to influence the interviewed, but some general laziness is also a possible cause. Incomplete questionnaires were discarded in the preliminary analysis, so that only 57% of the collected questionnaires could be used for the present study.

The typical visitor was already aware of the site or had heard about it from a friend, a relative or a colleague. He had an idea of what the experience was going to be like and was usually coming with a small group of similar-minded people (either friends or acquaintances). Most of the visitors revealed a creative spirit and an opening to innovation; in some cases they had their own musical instrument on the day.

The visitors who accepted to participate at the study were mainly males (60%) with an age comprised between 18 and 65. Male visitors mainly described their experience with sound as “enjoyable” and “pleasant” while their female counterpart (40%) mainly used words like “surreal” and “abstracted from the external world”. No particular description was reported for the garden without sound using the free text space.

Visitors resulted on average highly sensitive to noise (average value 3.6 over 5), especially the male ones (average value: 4 over 5).
The results of a preliminary analysis, without taking into account the confounding factors (e.g. sex, age and relationship with music), can be summarized as follows (see Figure 4):

- in most of the cases the perception of the road did not change, as the greater number of values (this guarantees that the intervention is only subtle and that alarm noises from the road can still be perceived);
- people who perceived the noise in an extreme way (answers 1 or 5 to Question 1 in absence of sound) may be not positively affected by a change in the soundscape;
- in a minor number of cases (corresponding to very sensitive visitors), the experienced annoyance increased when sound was switched ON;
- visitors with intermediate sensitivity were positively affected by the change in the soundscape, so that their annoyance decreased, sometimes in an extraordinary way.

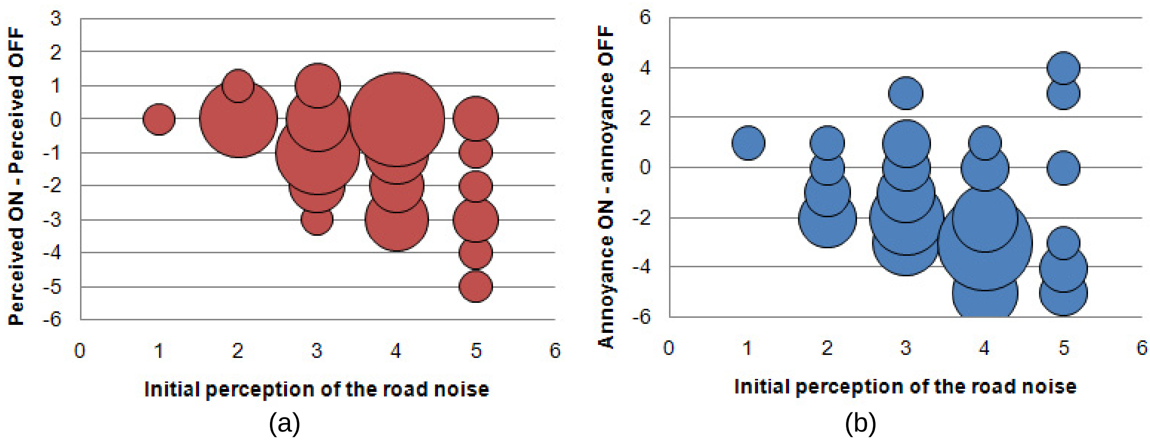


Figure 4: Summary of the results of the study during Giardino Sonoro open days in summer 2007. The two graphs report the comparison between sound ON and sound OFF for a fixed value of the initial perception of the noise (without sound emitters on), in terms of (a) perception and (b) annoyance. The size of the bubble in the graph indicates the percentage of answers over the total.

2.4 Conclusions

The transposition of the European Noise Directive by Member States has opened new frontiers to the research on cost/effective action plans for the preservation of urban quiet areas. In these sites, numerical indicators are needed to characterize the "quality of quietness", in order to judge the effects of the actions taken and to design effective measures.

In this cases, a predictive indicator like *Slope* can effectively help the designer of new environments (or the planner of noise improvement measures) giving a technical and quantitative indication on the direction to follow, to be developed afterwards using creativity and experience. Effects of the shape of the diffuser and of the acoustic compositions in Giardino Sonoro were investigated using *Slope* in previous studies[10] and they will not be discussed here. It is worth noticing that the use of *Slope* (or of a suitable set of indicators) allowed the designer to select the combination of sound and emitter to achieve a pre-determined quality of quietness (specified by the values of the indicators, according to a scale like the one in Figure 1b). In a few words, a good choice of indicators (not necessarily *Slope* alone) allows to design quietness using artificial soundscapes.

The present study has demonstrated the limits of classical psychoacoustical indicators in detecting the change of soundscape: even positive changes in the perception (assessed by questionnaires) can be classified as negative if only L_{Aeq} is taken as a measure of the change. It is worth highlighting the importance of this result for action plans based on the noise level only (like the ones that the END seems to promote, suggesting L_{den} as main indicator for annoyance): reducing the energy alone might go in the wrong direction. Exemplar is the case of streets closed to cars, where the number of complaints peaks as other sounds, less energetic but apparently more intolerable (like the fans of air conditioning units), take the place of traffic noise.

Further studies are needed to evaluate the weight of visual factors on the *Slope* indicator and to define its robustness. The assessment of perception should also be investigated for people experiencing the installations over longer periods of time (e.g. in a residential environment).

3 REFERENCES

1. European Commission, *Green Paper on Future Noise Policy*, COM(96) 540 (1996).
2. Sysmonds Group, *Definition, Identification and preservation of Urban & rural Quiet Areas*, Final Report under Service Contract ENV, C 1/SER/2002/0104R of the European Union, East Grinstead, UK (2003).
3. WG-AEN and WG-HSEA, *Quiet areas in agglomerations*, Interim Position Paper (2004).
4. Soundscape Support to Health program, at www.soundscape.nu
5. http://www.london.gov.uk/mayor/strategies/noise/docs/noise_strategy_all.pdf
6. G. Licitra, G. Memoli, Noise Indicators and Hierarchical Clustering in Soundscapes, *Proceedings of INTERNOISE 2005*, Rio de Janeiro (2005).
7. G. Licitra, G. Memoli, D. Botteldooren, B. De Coensel, Traffic noise and perceived soundscapes: a case study, *Proceedings of Forum Acusticum 2005*, Budapest (2005).
8. H. M. E. Miedema, Proceedings of the *WHO Technical meeting on exposure-response relationships of noise on health*, Bonn (2002).
9. Beaumont J., Petitjean E., *Driving Force, Pressure and State Indicators*, Technical meeting on noise indicators, Brussels - April (2003).
10. www.giardinosonoro.it See also www.soundexperiencedesign.com
11. G. Licitra, G. Memoli, Testing new solutions for action plans in quiet areas, *Proceedings of Euronoise 2006*, Tampere (2006).
12. E. Zwicker, H. Fastl, *Psycho-Acoustics, facts and models*, 2nd updated edition, Springer (1999).
13. See the *Noise Questionnaire Database* at http://eco.psy.ruhr-uni-bochum.de/nqd/nqd.php