**Edinburgh, Scotland**
**EURONOISE 2009**
**October 26-28**

# Uncertainties on the application of the Portuguese noise legislation

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## ABSTRACT

A new legislation on noise assessment and management was adopted in 2007 in Portugal. Under this law, industries, municipalities and other entities have to control and monitor noise, in accordance to certain standards and norms, which are not always easy to comply with. Those entities have the obligation to report the control and monitoring results to the authorities, showing their compliance with the limit values.

The Portuguese noise legislation has two different approaches to specify limit values: one based on the comparison with a maximum limit value and the other one referring to an annoyance limit value related with a difference between two values.

The maximum limit value refers to $L_{den}$ or $L_{night}$, which are distinct indicators for different types of noise, surroundings and population noise sensitiveness.

The annoyance value is the degree of community noise annoyance as determined by means of field measurements.

Besides these limits values, the legislation and the associated standards and norms have a methodology to reduce variability in noise measurements that could induce in different decisions.

In this work, rather than performing a comparison with the limit values, a sensibility analysis has been made with the main objective of discussing the efficiency of the law and the variability and uncertainty associated.

The main conclusion of this work shows, based on real and laboratory examples that the variability of the acoustic sign and the associated uncertainty are inherent to the characterization of noise level and the applicability of Portuguese noise Law is ambiguous.

## 1. INTRODUCTION

To describe environmental noises completely it is necessary to consider many different characteristics. It must be considered the sound pressure level of the noise and how this level varies over a variety of periods, ranging from seconds or minutes to seasonal variations over

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several months. At the same time, the frequency content of each noise will also determine its effect on people, as will the number of events when there are relatively small numbers of discrete noisy events. Combinations of these characteristics determine how each type of environmental noise affects people. Unfortunately, there is not a completely understanding of all complex links between noise characteristics and the resulting effects on people. Thus, current practice is to reduce the assessment of environmental noise to a small number of quite simple quantities that are known to be reasonably well related to the effects of noise on people (e.g. $L_{Aeq,T}$). These simple measures have the distinct advantage that they are relatively easy and inexpensive to obtain and hence are more likely to be widely adopted[1].

Many studies have suggested that the annoyance effect of a particular noise depends on how much that noise exceeds the level of ambient noise. This has been shown to be true for relatively constant noises, but has not been consistently found for time-varying noises such as aircraft noise[2].

After defining the measurement parameters, it is important, in addition to the measuring and monitoring strategy and to the implementation of international standards, the definition of a limit to control noise and protect human health.

The Portuguese noise Law[3] is essentially based on the determination of the noise indicators $L_{den}$ (day-evening-night level) and $L_n$ (night level) selected to verify compliance with maximum limits ($11^{th}$ Article - exposure limit values) and the annoyance criteria ($13^{th}$ Article) of the general regulation of noise (DL nº 9/2007 of January 17).

The noise indicators $L_{den}$ and $L_n$ are long-term average levels, as defined in Portuguese Standard NP1730:1996, determined during a representative series of periods of one year.

The day-evening-night level $L_{den}$ in decibels (dB) is defined by the following formula:

$$L_{den} = 10 \times \log \frac{1}{24}\left[13 \times 10^{\frac{L_d}{10}} + 3 \times 10^{\frac{L_e+5}{10}} + 8 \times 10^{\frac{L_n+10}{10}}\right] \tag{1}$$

The noise indicators $L_d$ ($L_{day}$), $L_e$ ($Le_{vening}$) and $L_n$ ($L_{night}$) corresponds to the equivalent continuous sound pressure level of long duration ($L_{Aeq,\,LT}$) and can be expressed by:

$$L_{Aeq,T} = 10\log\left[\frac{1}{n}\sum_{i=1}^{n} 10^{(LAeq,T)i/10}\right] \tag{2}$$

The beginning of the day period (and consequently the beginning of the evening and night) was chosen by the Portuguese Authorities to be 07.00 to 20.00 h, 20.00 to 23.00 h and 23.00 to 07.00 h local time.

The annoyance criterion is considered to be the difference between the $L_{Aeq}$ value indicator for ambient noise, and the LAeq value indicator of residual noise.

The ambient noise is defined in ISO 1996-1:2003[4] as total sound: totally encompassing sound in a given situation at a given time, usually composed of sound from many sources near and far during the occurrence of a particular noise activity or activities. The particular noise is defined in ISO 1996-1:2003 as the specific sound: component of the total sound that can be specifically identified and which is associated with a specific source.

The residual noise is defined by ISO 1996-1:2003 as the residual sound: total sound remaining at a given position in a given situation when the specific sounds under consideration are suppressed.

This criterion is applied to the three time intervals, day, evening and night with different values, and has to take account of tonal and impulsive noise and the activity duration. After the corrections the ambient noise is defined as assessment level ($L_{Ar}$). Limit values for the maximum limits and annoyance criteria are expressed in Table 1.

**Table 1**: *Limit Noise Values in Portuguese Law.*

| Maximum limit values | |
|---|---|
| $L_{den}$ dB(A)) | $L_n$ dB(A) |
| 55 (Sensitive zone) | 45 (Sensitive zone) |
| 65 (Mixed Zone) | 55 (Mixed Zone) |
| **Annoyance criteria** | |
| $L_{Aeq}$ (ambient noise+corrections) - $L_{Aeq}$ (residual noise) dB(A) | |
| Day | 5 |
| Evening | 4 |
| Night | 3 |

## 2. FIELD MEASUREMENTS

The present study describes a monitoring noise program in the surrounding area of a solid waste treatment plant (LIPOR II) near Porto, Portugal. The measurements of this program are performed since 1997. Since 2000, the measurements refer to the plant normal operation.

The main noise sources in LIPOR II surroundings are associated with the operation of the plant and the road traffic of a highway.

The waste treatment plant has a continuous operation labor during day and night, while the traffic volume during these periods varies, affecting the levels of the surrounding noise.

Measurements of ambient noise are made every trimester, and the residual noise measurements are made at the stops of the plant, which could be annual and planned, or not.

The monitoring of noise levels included 4 sites surrounding LIPOR II, located near houses, in areas considered particularly sensitive (Figure 1).

Point R1, located north to LIPOR II, maintains visual contact and it is subject to the direct propagation of sound levels from operation of the plant.

In points R2 and R3, the main noise sources are related to the general operations of LIPOR II, construction work and traffic of the highway. In Point R4, due to its proximity to the highway, the observed values of equivalent continuous sound level are the highest and result mainly from heavy vehicle traffic in this road.

The used measuring equipment is a precision sound level meter (type 1) Brüel & Kjær model 2260, equipped with a preamplifier Brüel & Kjær model ZC 0026 and a Brüel & Kjær microphone model 4189.

The determination of the $L_{Aeq}$ parameter was made according to the technique described in Portuguese Standard NP1730:1996, Part 1, 2 and 3.

The main conclusion of this monitoring noise program is that the operation of LIPOR II does not induce serious problems of noise pollution in the environment. Indeed, only in one point (R1), occur some exceedences to annoyance criteria. The results show high uncertainty associated with measurements of residual noise, which suggests great variability. In this context, this paper will only present the measurements made at point R1.

Tables 2, 3 and 4 show $L_{Aeq}$ measurements in point R1, for the day, evening and night periods, between the years 2001 and 2008.

Evening measurements appear for 2007 and 2008 because the definition of 3 periods appeared only in 2007 with the Law No 9 / 2007 of January 17.


**Figure 1**: Measurement Noise Points of LIPOR II.

**Table 2:** *Measurements of $L_{Aeq}$ value for ambient and residual noise in point R1- day.*

| Noise | Date | $L_{Aeq}$ (dB(A)) | Noise | Date | $L_{Aeq}$ (dB(A)) | Date | $L_{Aeq}$ (dB(A)) |
|---|---|---|---|---|---|---|---|
| Residual noise | 12.11.01 | 50.7 | Ambient Noise | 24.05.01 | 58.0 | 30.03.06 | 55.8 |
| Residual noise | 11.11.02 | 55.2 | Ambient Noise | 07.08.01 | 55.1 | 26.09.06 | 52.5 |
| Residual noise | 27.05.03 | 49.9 | Ambient Noise | 22.11.01 | 56.2 | 12.10.06 | 51.8 |
| Residual noise | 27.05.03 | 55.8 | Ambient Noise | 26.03.02 | 55.6 | 13.12.06 | 50.4 |
| Residual noise | 09.09.03 | 55.2 | Ambient Noise | 19.06.02 | 59.1 | 22.02.07 | 54.7 |
| Residual noise | 04.03.04 | 55.8 | Ambient Noise | 22.06.02 | 56.0 | 22.02.07 | 55.6 |
| Residual noise | 13.11.04 | 52.4 | Ambient Noise | 03.12.02 | 53.1 | 22.02.07 | 54.6 |
| Residual noise | 07.06.05 | 51.5 | Ambient Noise | 17.03.03 | 53.8 | 22.02.07 | 53.4 |
| Residual noise | 23.02.06 | 57.1 | Ambient Noise | 24.06.03 | 51.5 | 21.06.07 | 55.3 |
| Residual noise | 20.11.06 | 51.8 | Ambient Noise | 24.06.03 | 53.4 | 21.06.07 | 54.6 |
| Residual noise | 01.06.07 | 48.5 | Ambient Noise | 23.09.03 | 55.3 | 22.09.07 | 49.4 |
| Residual noise | 01.06.07 | 52.2 | Ambient Noise | 20.11.03 | 51.9 | 22.09.07 | 46.2 |

| Noise | Date | $L_{Aeq}$ (dB(A)) | Noise | Date | $L_{Aeq}$ (dB(A)) | Date | $L_{Aeq}$ (dB(A)) |
|---|---|---|---|---|---|---|---|
| Residual noise | 02.06.07 | 48.3 | Ambient Noise | 10.02.04 | 56.3 | 05.04.08 | 49.9 |
| Residual noise | 02.06.07 | 50.0 | Ambient Noise | 16.06.04 | 56.0 | 05.04.08 | 51.6 |
| Residual noise | 15.02.08 | 50.9 | Ambient Noise | 29.11.04 | 54.1 | 05.05.08 | 52.2 |
| Residual noise | 15.02.08 | 51.6 | Ambient Noise | 24.11.04 | 51.5 | 05.05.08 | 53.8 |
| Residual noise | 16.02.08 | 47.4 | Ambient Noise | 04.03.05 | 54.4 | 05.07.08 | 47.7 |
| Residual noise | 30.10.08 | 53.0 | Ambient Noise | 07.06.05 | 53.8 | 05.07.08 | 51.7 |
| | | | Ambient Noise | 20.09.05 | 54.8 | 25.09.08 | 49.5 |
| | | | | 24.11.05 | 53.8 | 25.09.08 | 49.0 |
| | | | | 27.12.05 | 57.7 | | |

**Table 3:** *Measurements of $L_{Aeq}$ value for ambient and residual noise in point R1- evening.*

| Noise | Date | $L_{Aeq}$ (dB(A)) | Noise | Date | $L_{Aeq}$ (dB(A)) | Date | $L_{Aeq}$ (dB(A)) |
|---|---|---|---|---|---|---|---|
| Residual noise | 01.06.07 | 46.6 | Ambient Noise | 22.02.07 | 51.1 | 05.04.08 | 48.2 |
| Residual noise | 02.06.07 | 47.6 | Ambient Noise | 22.02.07 | 50.1 | 05.05.08 | 46.7 |
| Residual noise | 15.02.08 | 48.8 | Ambient Noise | 21.06.07 | 49.6 | 05.07.08 | 50.6 |
| Residual noise | 16.02.08 | 44.7 | Ambient Noise | 22.09.07 | 50.4 | 25.09.08 | 48.3 |
| Residual noise | 30.10.08 | 47.5 | Ambient Noise | 28.09.07 | 55.8 | | |

**Table 4:** *Measurements of $L_{Aeq}$ value for ambient and residual noise in point R1- night.*

| Noise | Date | $L_{Aeq}$ (dB(A)) | Noise | Date | $L_{Aeq}$ (dB(A)) | Date | $L_{Aeq}$ (dB(A)) |
|---|---|---|---|---|---|---|---|
| Residual noise | 10.11.01 | 42.8 | Ambient Noise | 24.05.01 | 49.0 | 27.09.06 | 51.0 |
| Residual noise | 12.11.02 | 47.4 | Ambient Noise | 07.08.01 | 45.1 | 13.10.06 | 48.9 |
| Residual noise | 28.05.03 | 48.9 | Ambient Noise | 22.11.01 | 46.9 | 14.12.06 | 50.0 |
| Residual noise | 28.05.03 | 42.0 | Ambient Noise | 26.03.02 | 47.1 | 22.02.07 | 50.8 |
| Residual noise | 10.09.03 | 48.2 | Ambient Noise | 19.06.02 | 48.9 | 23.02.07 | 50.2 |
| Residual noise | 05.03.04 | 49.6 | Ambient Noise | 22.07.02 | 48.6 | 22.02.07 | 50.7 |
| Residual noise | 14.11.04 | 50.6 | Ambient Noise | 04.12.02 | 49.1 | 23.02.07 | 50.4 |
| Residual noise | 09.06.05 | 50.3 | Ambient Noise | 19.03.03 | 49.0 | 21.06.07 | 48.2 |
| Residual noise | 24.02.06 | 47.4 | Ambient Noise | 25.06.03 | 47.7 | 22.06.07 | 47.4 |
| Residual noise | 21.11.06 | 44.9 | Ambient Noise | 24.09.03 | 52.5 | 22.09.07 | 49.7 |
| Residual noise | 01.06.07 | 44.2 | Ambient Noise | 21.11.03 | 49.8 | 23.09.07 | 50.2 |
| Residual noise | 02.06.07 | 44.6 | Ambient Noise | 11.02.04 | 51.6 | 28.09.07 | 51.2 |
| Residual noise | 02.06.07 | 46.1 | Ambient Noise | 17.06.04 | 50.1 | 29.09.07 | 51.8 |
| Residual noise | 03.06.07 | 44.7 | Ambient Noise | 30.09.04 | 52.0 | 05.04.08 | 46.2 |
| Residual noise | 15.02.08 | 48.7 | Ambient Noise | 29.11.04 | 48.5 | 06.04.08 | 46.6 |
| Residual noise | 16.02.08 | 45.2 | Ambient Noise | 10.03.04 | 49.9 | 05.05.08 | 47.3 |
| Residual noise | 30.10.08 | 44.3 | Ambient Noise | 08.06.05 | 48.5 | 06.05.08 | 45.1 |
| | | | Ambient Noise | 21.09.05 | 49.3 | 05.07.08 | 49.7 |
| | | | Ambient Noise | 25.11.05 | 51.8 | 06.07.08 | 48.4 |
| | | | Ambient Noise | 28.12.05 | 52.5 | 25.09.08 | 47.0 |
| | | | | | | 26.09.08 | 46.4 |

The analysis of the field campaigns showed that the measured values dispersion is high, with a standard deviation for residual noise, of 2.8 for the day measurements, 1.5 for the evening measurements and 2.6 for the night.
For the above measurements, the annoyance criteria was applied, taking into account two different methodologies: for each annual set of samples and for all samples (2001-2008).
Figures 2, 6 and 4 present the annoyance criteria for each annual set of samples and for the total.
As showed in the figures below the annoyance criteria fluctuated between a minimum value of 1.3 dB(A) and a maximum of 6.0 dB(A), in the day, 1.4 and 5.0 in the evening and 0.5 to 5.0 in the night.
The variability of residual noise for the day period is so high that in some measurements the ambient noise is equal or lower than the residual noise (2003, 2006 and 2008). This increase in variability of residual noise measurements was already noted in the controlled measurements.
The noise measurements for the Monitoring Noise Program of Urban Solid Waste Incineration LIPOR II, show a great variability in the acoustic environment of the surrounding area.
This high uncertainty affects legislation comparison, as the obtained value may or may not be legislative compliant.

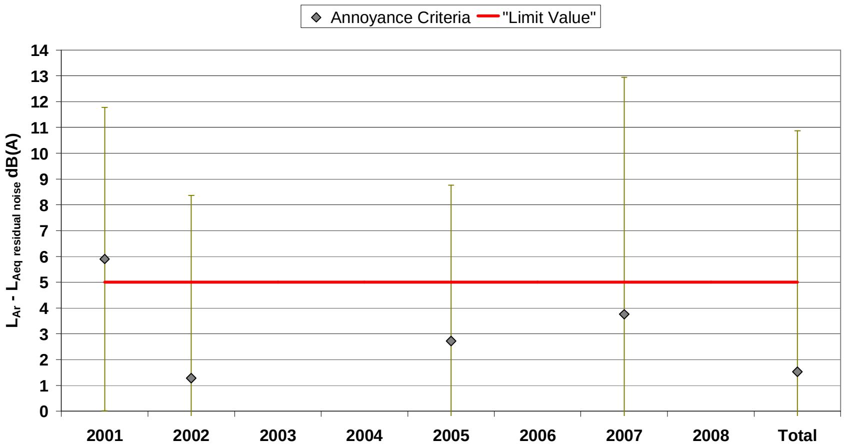


**Figure 2**: Annoyance criteria for LIPOR measurements - day.

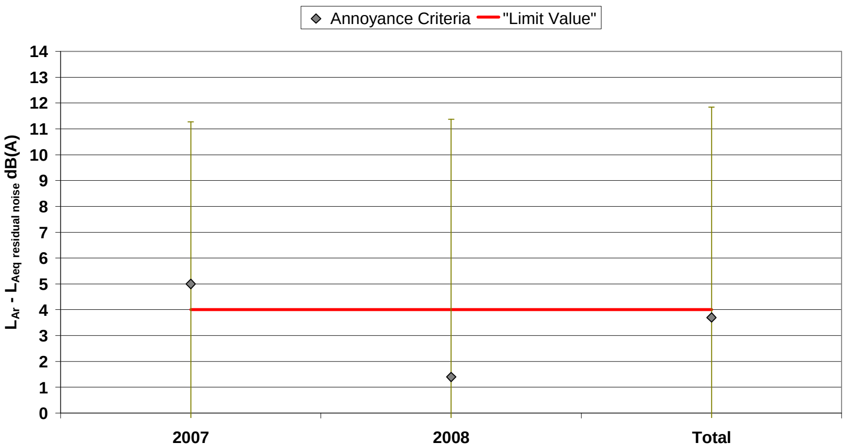


**Figure 3**: Annoyance criteria for LIPOR measurements - evening.

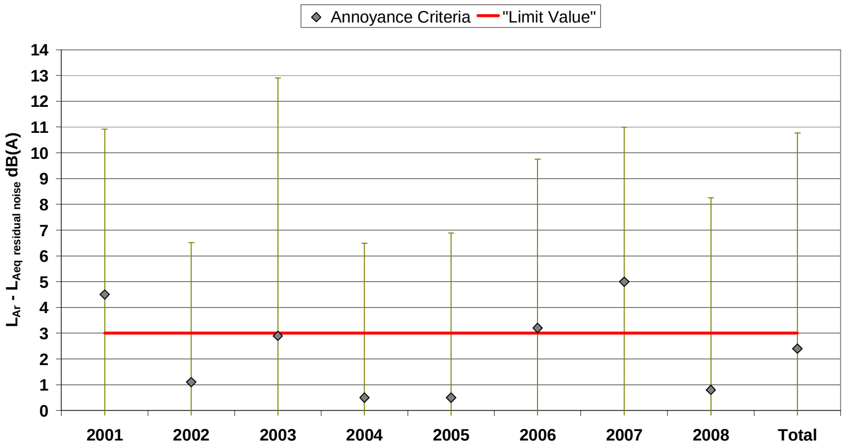


**Figure 4**: Annoyance criteria for LIPOR measurements - night.

## 2. MEASUREMENTS IN CONTROLED CONDITIONS

In November 2007 and January 2008 a Proficiency Acoustic Test for the annoyance criteria was made in Portugal. This test was held by an independent entity (Relacre)[5].
The Proficiency Acoustic Test was based on the measurement of sound pressure from a noise source for the annoyance criteria calculation, according to NP1730:1996 standard[6], harmonized with ISO 1996-1:1982, 1996-1, 2:1987, and following the "Circular No. 2 / 2007 IPAC"[7] and the Annex I of the Law No. 9 / 2007.
The objective of any Proficiency AcousticTest is to compare several laboratories analytical results in the same sampling conditions. It wasn't technically possible to perform those samplings simultaneously, so the test lasted for 3 months, during which it was essential to ensure the lowest variability possible of the sound source and the conditions of sound propagation. Assuming that in these highly controlled conditions the variability will be negligible, the result variability is due essentially to the adoption of different strategies of sampling and the use of different measuring equipments.
For this test 2 adjacent rooms were used. In the first one (designated by emission room) a sound source was placed; while in the second one (receiving room) the measurement of the $L_{Aeq}$ was performed. Each laboratory measured the noise produced by a stationary source, and had 30 minutes to characterize the $L_{Aeq}$ of ambient and residual noise.
The specific sound level wanted to simulate a noise produced by a source with an operation period between 07-20 h. Data were interpreted from the perspective of compliance with the general regulation noise[5].
From the 67 laboratories participated in this test, 34 were accredited by the Portuguese Accreditation Institute (IPAC). The conclusions found that no unsatisfactory performance evaluation was detected. Four of the participating laboratories had a questionable performance. By Grubb's method, which allows the detection of aberrant values based on variability, two laboratories were eliminated[5].
Figures 5 and 6 present the obtained values for the ambient and residual noise measured by the participating laboratories.

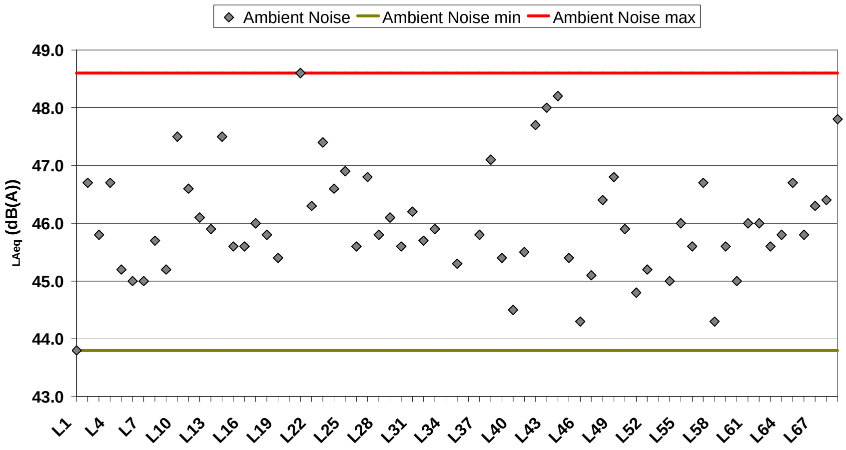


**Figure 5**: Ambient Noise measured at Proficiency AcousticTest.

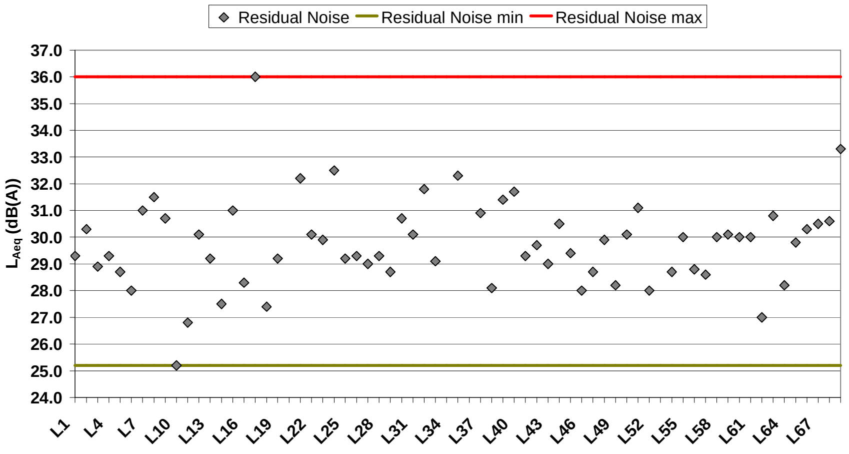


**Figure 6**: Residual Noise measured at Proficiency AcousticTest.

The results show that the dispersion of measured values can be high, with a standard deviation of 1.66 for residual noise, and 1.92 for ambient noise. The average linear residual noise was 29.7 dB(A) fluctuating between a minimum value of 25.2 dB(A) and a maximum of 36.0 dB(A). The range of residual noise considered valid expands up to 10.8 dB (A).

For ambient noise it was obtained a maximum value of 48.6 dB(A) and a minimum of 43.8 dB (A). The linear average value of this parameter was 46.0 dB (A).

The main conclusion to be drawn from this analysis is the fact that, despite the highly controlled conditions, noise measurements differ considerably, even when measured by accredited laboratories. In residual noise measurements there is a clear increase in variability, and a very high dispersion of the measured values.

Considering the day annoyance criteria limit of 5 dB (A) (Table 1), the variability level of ambient noise measurements will be in the same order of magnitude of this limit and that the variability level of residual noise is twice this criterion.

This problem worsens when, the annoyance criteria is determined, which is the difference between the assessment level and the $L_{Aeq}$ of residual noise. Figure 7 shows the annoyance criteria and uncertainty values, reported by each laboratory.

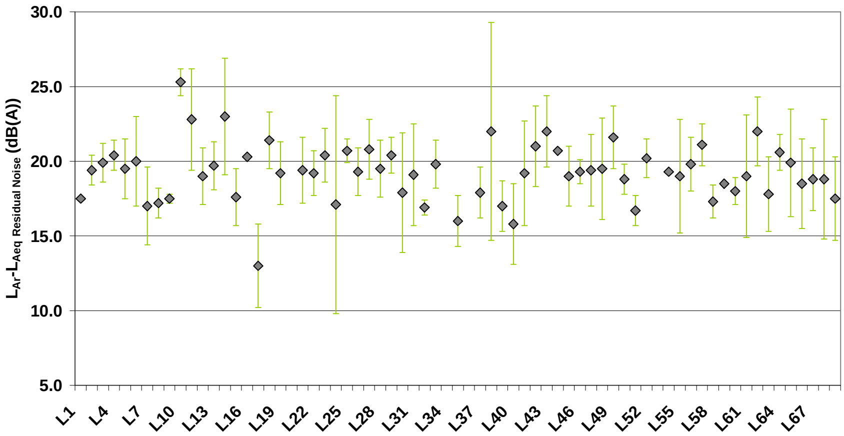


**Figure 7:** Annoyance criteria at Proficiency AcousticTest.

The annoyance criteria reported varies between 13.0 dB (A) and 25.3 dB (A), the linear average value was 19.3 dB (A) and standard deviation 1.9 dB (A).
In this case, annoyance criteria had a value quite high and clearly above the threshold level of 5 dB(A). However, if the noise was lower and the annoyance criteria closer to the legal limit, the participating laboratories could withdraw completely different conclusions.
Note that the range of standard deviation is 3.8 dB (A), which exceeds the threshold for the annoyance criteria during the night (3 dB (A)) and approaches significantly to the limit day value (5 dB (A)). The associated uncertainty reported by several laboratories turns the analyses more complex.
The main conclusion from the present study is that the variability in controlled conditions is sufficiently high to make the annoyance criteria application very ambiguous.

## 4. CONCLUSIONS

The Portuguese law defines the annoyance criteria as an indicator to assess the actual impact of a source of noise on the environment.
One of the main conclusions of this paper, clearly demonstrated through laboratory and real examples is that the variability of the acoustic signal and the resulting uncertainty are inherent in the characterization of the noise level from anywhere.
The analysis developed here, evidences the complexity of acoustic measurements and the presence of a strong variability in sound levels, which causes unavoidable uncertainties in the measured results. Obviously this variability itself varies from place to place. However, the results obtained in LIPOR II show that the acoustic variability also depends on the reference period considered. The characterization studies of environmental noise, and in particular, the annoyance criteria are developing in a deterministic and less interpretative way, instead of seeking the variation, typically seeks the representativity. This paper shows the difficulty of obtaining a single value, considered as representative of a sound environment on a given place, especially when this value is the result of a limited number of measurements with a short sampling period (10 to 30 minutes).
Some studies[8] indicate a complementary way for seek representative measurements: the demand for representation must be accompanied by clear identification of the variability

associated with a particular characterization. Only then you can manage this variability and the uncertainty of risk assessment and the decision associated to it.
The proposed approach is not an attempt to suggest new techniques for monitoring or data treatment, but to force a systemic analysis and require the recognition of the inherent variability characterization. This methodological proposal is not intended to reduce uncertainty but to know it, and identify, in each case, the aspects in which this uncertainty is more important.
It is necessary to identify the factors that may affect the variability of each measurement and work with this new information. Although duly supported by the guidelines of NP-1730, this recommendation becomes a change in the established practice and may cause reluctance by the technical community involved in this problem, namely the administration with environmental responsibilities.

## ACKNOWLEDGMENTS

The authors acknowledge the Urban Solid Waste Incineration LIPOR II for the access to the monitoring noise data used in this work.

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