Measuring and identifying background noises in offices during work hours

E Rossi$^{1, *}$, D De Salvi$^{1}$, D D'Orazio$^{1}$ and M Garai$^{1}$

$^1$ DIN, Department of Industrial Engineering, University of Bologna

* elena.rossi56@unibo.it

Abstract. In offices and working places, noise analysis aims at enhancing the acoustic comfort, the concentration and the oral communication quality. According to the current regulations, background noise is evaluated in unoccupied conditions, but it is interesting to know its dynamic behaviour in occupied state. The knowledge of the noise components may be useful for improving the estimation of comfort parameters, such as the distraction distance (ISO 3382-3) or Speech Transmission Index (IEC 60268-16). The present study suggests a method to extract background noises values with statistical techniques from recordings made during work hours with sound level meters. Statistical techniques were used for the analysis of short-time sound pressure levels obtained over long-term recordings: Gaussian Mixture and Percentile Levels. Noise sources are identified from octave bands analyses. Measurements done using Gaussian Mixture were compared with the ones done with Percentile Levels. Results show some differences between the two techniques.

1. Introduction

Acoustic comfort in offices is an important aspect to provide a high level of productivity and quality of work. Background noise is the key factor of the acoustic comfort in offices and it can be considered one of the most important parameters for the acoustical office design [1]. Colle and Welsh highlighted as the distraction in the work place is not strictly related to the pressure level but it’s due to the speech intelligibility [2]. Thus, if the noise carries information, like the speech of the neighbours in the office, there’s a lack of productivity [3]. Worker’s privacy is measured with the Speech Transmission Index (STI), defined by the IEC 60268-16 [4]. It depends on the acoustical properties of the room and the background noise. This criterion should be measured in unoccupied condition (with all devices switch off) and then adjusted in post processing with background noise. Thus, the measurement of the latter is very important since the noise reduces the speech intelligibility of the other people’s communications. For this reason, the background noise should be neither too low nor too high [5]. The ISO 3382-3 [6] specifies the privacy criteria: the distraction distance ($r_D$) and the spatial decay rate of speech per distance doubling ($D_{2,5}$). Such criteria depend on the noise sources, so a proper measurement of the background noise means understanding the acoustic comfort.

The sound field in an enclosed space is different if it is in occupied or unoccupied state so the sound sources could have more than one behaviour, in addition, in occupied state there are further sound source, i.e. the equipment and the human activities. This dynamical approach describes the acoustic of a place more realistically. Hodgson et al. [7] suggested a method to measure the student activity during lecture with a statistical technique. Dehlbæk et al. [8] applied this method in order to measure the human activity noise in open-plan offices. Measuring a work day with a sound level meter, the occupied and unoccupied state of an office can be analysed. Statistical distribution of the stored data brings order of the recorded sound pressure levels highlighting which are the most common. Progressively statistical algorithms permit to study the distribution curves and point out the sound levels of the various sources in the office. The present study deals with two statistical techniques in order to analyse in deep the...
background noise. The Percentile Levels technique is a standard procedure to evaluate the background noise while the Gaussian Mixture Model is a newer approach and allows to understand the sound field in a more realistic way.

2. Statistics of sound pressure levels
A statistical analysis of the collected data of a sound level meter distributes the sound pressure levels basing on their occurrences. In this way it is possible to highlight the most frequent levels during the work day. If the frequency (in the statistical meaning) of a sound pressure level is high it means that there is a sound source working at that level in continuum. Studying the occurrences in each octave band it is useful to distinguish the kind of sound source which is operating. Two statistical methods were used for the survey: Percentile Levels (PL) and Gaussian Mixture Model (GMM). Percentile Levels indicate the levels which are exceeded for a percentage of time, e.g. the $L_{90}$ is the corresponding sound pressure level exceeded for the 90% of the recorded time. Gaussian Mixture Model fits the asymmetrical curve of the occurrences of sound pressure levels as a sum of gaussian curves. The model fits the data with the Maximum Likelihood estimation that assigns points to the corresponding cluster. This estimation is derived with the EM algorithm [9]. Each mean of these corresponds to a sound pressure level’s source.

![Percentile levels and Occurrences](image1)

**Figure 1.** Example of the statistical distribution of the data with the two techniques: on the top left Percentile Levels distribution, on the top right occurrences which can be fitted with GMM. On the bottom left an example of the corresponding $L_{90}$ and on the bottom right an example of fitting made with GMM.
3. Method
A small open-plan office, with four workplaces, was used as case study in this preliminary study. Sound pressure levels were recorded for an entire workday with a sound level meter with 0.1 second of sample time for acquisition. Thus, both unoccupied and occupied state of office were observed. Thereafter, with the time history, it was possible to separate the stored data and analyse each condition. For the GMM method the algorithm was set random which means that the number of the gaussian curves was calculated automatically in order to optimize the fit. The number of gaussian curves obtained and the corresponding standard deviation were extracted. The standard deviation (s.d.) permits to identify the nature of the source, whether it is mechanical or random like the anthropic activities. As suggested by literature, a value of s.d. greater than 5 dB can be considered as human activity noise [10]. For Percentile Levels the L₉₉, L₉₅ and L₉₀ were extracted as the standard procedures require. This analysis was conducted for each octave band from 125 Hz to 4000 Hz.

4. Results
The results for the two techniques are shown in table 1 for the Percentile Levels method and Table 2 for the Gaussian Mixture Model analysis. In table 2, for the GMM technique, only the mechanical sources are shown. Figure 2 shows the relationship between the means and the standard deviation of every gaussian curve. The outliers represent the human activity part of the measured background noise so, in this work, are not considered.

| Table 1. Results of the measured background noise (in dB) done with Percentile Levels technique. |
|---|---|---|---|---|---|---|
| **Percentile Level** | **Frequency octave band** | 125 Hz | 250 Hz | 500 Hz | 1000 Hz | 2000 Hz | 4000 Hz |
| L₉₉ | 26.9 | 24.5 | 21.6 | 18.2 | 16.6 | 18.9 |
| L₉₅ | 28.6 | 25.9 | 22.9 | 19.2 | 17.2 | 20.4 |
| L₉₀ | 29.5 | 26.7 | 23.7 | 19.9 | 17.5 | 20.7 |

| Table 2. Results of the measured background noise done (in dB) with Gaussian Mixture Model technique. The means and the standard deviations (s.d.) are shown. |
|---|---|---|---|---|---|---|
| **Number of Gaussian** | **Frequency octave band** | 125 Hz | 250 Hz | 500 Hz | 1000 Hz | 2000 Hz | 4000 Hz |
| 1 | 31.1 (1.9) | 26.8 (1.4) | 23.5 (1.2) | 19.7 (1.0) | 17.2 (0.4) | 19.0 (0.4) |
| 2 | 34.6 (3.3) | 28.5 (1.0) | 25.7 (1.1) | 21.3 (0.8) | 17.9 (0.3) | 20.8 (0.3) |
| 3 | - | 30.5 (1.0) | 27.9 (1.0) | 23.1 (1.1) | 18.6 (0.4) | 21.2 (0.2) |
| 4 | - | 32.9 (1.4) | 30.2 (1.1) | 25.9 (1.9) | 19.6 (0.6) | 21.7 (0.2) |
| 5 | - | 36.2 (2.6) | 33.1 (1.7) | 31.2 (3.9) | 21.1 (0.9) | 22.1 (0.3) |
| 6 | - | - | 37.1 (2.9) | - | 23.2 (1.2) | 22.8 (0.7) |
| 7 | - | - | - | 26.3 (1.7) | 24.4 (1.6) |
| 8 | - | - | - | 30.4 (3.0) | 27.9 (3.2) |

| **Levels’ sum of sources** | 36.2 | 39.3 | 39.8 | 33.3 | 33.3 | 32.4 |
Figure 2. Relationship between means obtained by the GMM clustering and the standard deviation for each octave band. The grey areas indicate the background noise values considered, while the outliers represent the human activity noise.
5. Discussions

A more complex statistical approach with the Gaussian Mixture Model allows to highlight every sound source in an enclosed space regardless of its nature, mechanical or human. Results show how GMM brings back more values than PL. The random algorithm permits to extract a certain number of clusters, thereafter the distance between the means and their standard deviations can be reconducted to a kind of source. Little differences between the means could be connected to the same source while a tiny standard deviation indicates the mechanical nature of the source. In fact, a little standard deviation means that a source produces a specific sound pressure level in continuum during time. Quite the opposite, high standard deviation means a more accidental nature of the source, like the human activity. This is a stronger method than Percentile Levels one, since, in order to obtain the same results with the latter, is fundamental to know the percentage of exceed time of a certain source. The comparison between the two methods shows how the PL technique underestimates the measured values.

6. Conclusions

Identifying sound sources in a work space is an important aspect in order to bring a high acoustical comfort and improve the productivity. This study compares two statistical techniques to highlight their differences in distinguishing the various sources. The Percentile Levels technique is a standard method of analysis and it is compared with the Gaussian Mixture Model one which represents a newer approach to the statistical data obtained by a sound level meter. GMM method allows to identify not just the number of sources present in the room but their nature too. In fact, with the standard deviation it is possible to analyse the kind of source, if it is high then the source works in a larger range of sound pressure levels, thus it can’t be considered as mechanical but more random like the human activity. This new approach of analysis permits a deeper understanding of the acoustical field in an enclosed space in order to operate more accurately in the correction of the criteria which describe the acoustical quality of the space, e.g. the STI, and the design interventions to achieve a better comfort of the work flow.

References

[1] Hongisto V, Keränen J, Larm P, 2004 Acta Acustica, Simple model for the acoustical design of open-plan offices 90 481 - 495
[2] Colle A, Welsh A, 1976 J. of Verb. Learn. and Verb. Behav., Acoustic masking in primary memory 15 17 - 31
[3] Hongisto V, Virjonen P, Keränen J 2007 19th International Congress on Acoustics, Madrid, Spain, Sept 2 - 7, Determination of acoustic conditions in open offices and suggestions for acoustic classification
[4] IEC 60268-16:2011, Sound system equipment - Part 16: Objective rating of speech intelligibility by speech transmission index
[5] Rindel J H 2018 DAGA, Munich, Germany, Mar 19 – 22, Open plan office acoustics – a multidimensional optimization problem
[6] ISO 3382-3:2012, Acoustic – Measurement of room acoustic parameters – Part 3: Open plan offices
[7] Hodgson M, Rempel R, Kennedy S, 1999 J. Acoust. Soc. Am., Measurement and prediction of typical speech and background noise, 105(1) 226 - 233
[8] Dehlsbæk T S, Jeong C, Brunskog J, Petersen C M, Marie P, 2016 Internoise, Hamburg, Germany, Aug 21 – 24, The effect of human activity noise on the acoustic quality in open plan offices
[9] Dempster A P, Laird N M, Rubin D B 1977, Journal of the Royal Statistical Society, Maximum Likelihood for Incomplete Data via the EM Algorithm (with discussion) Ser. B, 39, 1-38
[10] Iannace G, Ciaburro G, Trematerra A, 2018 Buildings, Heating, Ventilation, and Air Conditioning (HVAC) Noise Detection in Open-Plan Offices Using Recursive Partitioning, 8(12) 169