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INTEREST OF PREDICTIVE SIMULATION FOR NOISE LEVEL ASSESSMENT AT THE WORK PLACE.

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ABSTRACT

Sound level in an industrial room depends on a large number of parameters : the sources of noise, the room geometry, the wall absorption properties, the fittings etc. It is interesting to be able to predict sound levels in a given industrial room in order to adapt the acoustic treatment in conjunction with a better fitting distribution. A numerical simulation software " RAYSCAD+ " designed by National Institute for Research and Safety in occupational health has been developed in order to give a computer-based tool to people in charge of prevention of occupational risks. This paper is intended to present some results of numerical simulations from actual situations in different activities.

1 - INTRODUCTION

French statistics about noise at work say that many workers (25%) are exposed to noise during their occupational activities. 13% of the workers, are exposed to sound level over 85 dB(A). According to occupational physicians, 75% of them could generate a pathology although individual hearing protectors are given to 60% of the exposed workers. The pathology appearance probability is important compared to the number of workers having an individual protector, because the efficiency of this kind of protector (earmuffs, earplugs,...) is dependent on the effective wearing time. In actual situations, workers do not always wear the individual protectors in noisy environment because they are sometimes uncomfortable, particularly for long periods and can induce some disagreement during work for example if workers have to talk to each others. The more efficient protection against noise yet is the noise control which can be obtained by designing low sound level machines or for machines already installed, by utilizing equipment enclosure, insulated barriers, ... Nevertheless, very often the machinery enclosure is not applicable if the employee has to frequently - check process implementation - adjust machine controls - supply with raw matter .... So, if any action is impossible on the noise source, and if time exposure cannot be reduced (employee rotation), the last parameter to work on is the room (acoustic behavior of the walls, the ceiling, the floor, the fittings).

2 - GENERAL PRESENTATION OF THE SIMULATION SOFTWARE

The 3D simulation software designed by the National Institute for Research and Safety in occupational health uses ray-tracing technique which consists of emitting " sound rays ", following their path in the room and recording their successive reflections by walls or obstacles. This technique takes into account many parameters such as the actual room geometry, the presence of screens, obstacles (cabins, ...) and the influence of wall section with different absorption coefficients. If the acoustic power of all the noise sources in the room are known, this predictive model can calculate sound levels in empty or fitted rooms, noise map for a given room and spatial sound energy decay curve.

3 - SPATIAL SOUND ENERGY DECAY CURVE

A criterion which allows to define the acoustic characteristics of an industrial room is the reduction of sound level per doubling distance (DL) of the spatial decay curve recorded in a clear area of the room. With an omnidirectional reference sound source, the spatial decay curve gives the sound level measured at various points depending on their distance from the sound source. In most industrial rooms, this curve can be modeled for the first 30 m by a straight line as a function of the logarithm of distance. The reduction of sound per doubling distance DL of the spatial decay curve, expressed in dB(A), is independent of the acoustic power of source but strongly depends on reverberation due to the room. A DL of 0 dB corresponds to the case of a highly reverberant room (diffuse field); a DL of 6 dB corresponds to the case of an ideally treated room (free field).
This criterion is applied in the French regulations (order of 30 august 1990) which require that any room in which noisy machinery is to be installed must be designed so as to minimize the reverberation of sound on the surfaces when such a reverberation, assessed by a predictive acoustic method, would cause an increase in exposure level of 3 dB(A) or more. If the increase of exposure level cannot be assessed, measurements must be carried out in the room. The results (measured DL) are compared to the values given in the regulations (required DL). For example, in a fitted room the required DL is given by the following formulas, where S is the floor surface of the room :

$$
\begin{aligned}
&DL = 3\ \text{dB(A)} && \text{if } S \leq 210\ \text{m}^2 \\
&DL = 1{,}5 \log S - 0{,}5 && \text{if } 210 < S \leq 4600\ \text{m}^2 \qquad \textbf{(1)} \\
&DL = 4\ \text{dB(A)} && \text{if } S > 4600\ \text{m}^2
\end{aligned}
$$

4 - PRESENTATION OF THE ACTUAL SITUATIONS

Three actual situations from the field are presented hereafter.

- An hospital-based laundry, where automated equipment induce high level of noise.
- A bottling workshop which is a well-known noisy environment.
- A swimming-pool where sound sources are not machines but people.

For every case, an acoustic survey has been carried out which can be summarized as follow :

- Measurement in the field of useful acoustic parameters.
- Simulation based on the measured acoustic parameters in order to get initial conditions.
- Predictive simulation after introduction of new acoustic parameters (acoustic treatment).
- Comparison between initial and final conditions and noise abatement assessment.

5 - LAUNDRY ROOM IN AN HOSPITAL

This room is dedicated to the ironing of the hospital linen. The washing and drying processes are performed in another room. The dimensions and fittings of the laundry are indicated on figure 1. The room surface is 397 m², the room height is 4m. The main sources of noise are the automated ironers, the linen folders and exhaust ventilation. Employees were daily exposed to 85 dB(A). The clear areas were limited in the room due to a big volume of linen storage. The predictive acoustics survey has been carried out as follow :

1 - Measurement of spatial sound decay in the laundry in order to characterize the room before any acoustic treatment (Measured DL).
2 - Simulation of the spatial sound decay in order to get initial conditions which matched with field situation (simulated DL).
3 - Simulations of the spatial sound decay, with an absorbent ceiling (absorption coefficient $\alpha s = 0,6$ and $\alpha s = 0,8$) (predictive DL).
4 - Measurement of spatial sound decay in the laundry after treatment of the ceiling and comparison with the simulation results (Measured DL).

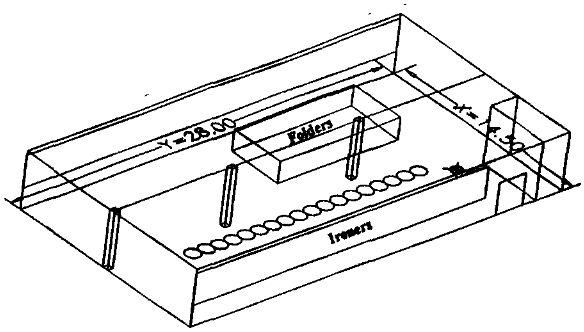


Figure 1

The results of the survey are gathered in table 1. According to the French regulations, the required DL for the room is **3,4 dB(A)** (see equations (1)).

Measured **DL** before acoustic treatment (1)	Simulated **DL** before acoustic treatment (2)	Simulated **DL** with $\alpha S_{CEILING}$ = **0,6** (3)	Simulated **DL** with $\alpha S_{CEILING}$ = **0,8** (3)	Measured **DL** after acoustic treatment (4)
3,2 ± 0,3 dB(A)	3,1 ± 0,2 dB(A)	3,7 ± 0,3 dB(A)	4,2 ± 0,4 dB(A)	3,9 ± 0,3 dB(A)

Table 1

Results analysis

The laundry room has been characterized by the spatial sound decay according to the French regulations. The measured DL was too low and the hospital management decided to reduce noise exposure of employees in order to reach the required level. Due to the room configuration and the activity, it was decided to limit the acoustic treatment to the ceiling. In that way, several simulations were run with material having different absorption quality : $\alpha_{SCEILING}$ = **0,6** and **0,8**. Although, for both cases, the results were conform to the regulations, the noise abatement achieved with $\alpha_{SCEILING}$ = **0,6** was not considered significant enough by the hospital management. So, the ceiling was covered with absorbent panels ($\alpha_{SCEILING}$ = **0,8**) which gave a measured DL of 3,9 ± 0,3 dB(A). After the acoustic treatment, the actual ceiling height was 0,9m lower than the simulated one. This parameter can partially explain the discrepancy observed between the simulation and the field results.

6 - BOTTLING WORKSHOP

This room is dedicated to bottling spirits. Three main automated bottling lines receive empty bottles from palettes which supply the conveyor line input. Bottles are filled, cocked, and ticketed before being loaded on palettes at the conveyor line output for expedition. All the machinery and bottles shocks along the three conveyors are noise sources which induce an acoustic pressure over 86 dB(A) in the workshop. The dimensions and fittings of the room are indicated on figure 2. The room surface is 1140 m², the room height is 4m. As the sound level was high, it was decided to carry out an acoustic survey including simulations of the room in order to be able to assess the final noise reduction which was reasonably expectable.

The acoustic survey was the following :

1 - Measurements of sound levels (acoustic pressure) at different places, in order to get an initial noise map.
2 - Determination of sound power sources by an intensimetric method or by acoustic pressure measurement.
3 - Measurement of spatial sound decay in the bottling workshop in order to characterize the room before any acoustic treatment (Measured DL).
4 - Simulation of the workshop, before any treatment, in order to verify that the results matched well with the field conditions.
5 - Simulations of the workshop after applying different acoustic treatments.
6 - Measurement of spatial sound decay after acoustic treatment of the workshop (suspended absorbers).

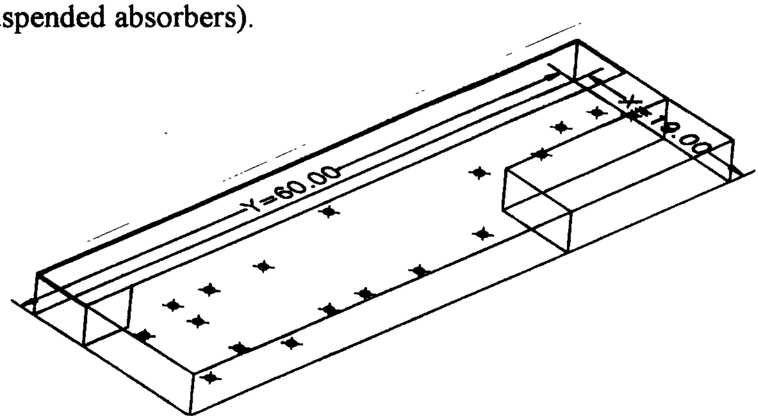


Figure 2

The figure 3 is the noise map resulting from the simulation of the workshop without any acoustic treatment. The figure 4 is the noise map obtained in the same way, after installing suspended absorbers having absorption coefficient of 0,8.

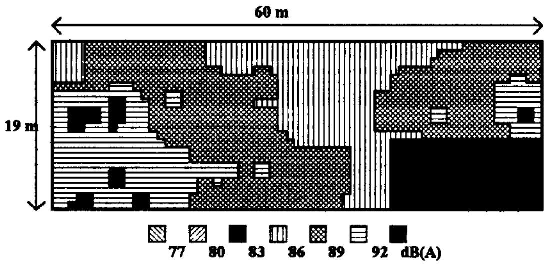


Figure 3 : initial sound levels

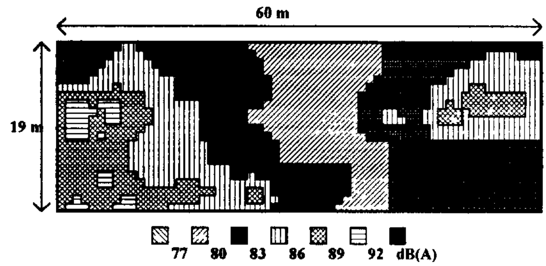


Figure 4 : Final sound levels

The results of the survey are gathered in table 2. According to the French regulations, the required DL for the room is **4 dB(A)** (see equations (1)).

Measured sound levels before acoustic treatment (1)	Measured **DL** before acoustic treatment (3)	Simulated sound levels with suspended absorbers (5)	Simulated **DL** of the room with suspended absorbers (5)	Measured **DL** after acoustic treatment (5)
86 to 95 dB(A)	3,7 ± 0,2 dB(A)	80 to 92 dB(A)	5,2 ± 0,2 dB(A)	5,1 ± 0,3 dB(A)

Table 2

Results analysis

The first measurements made in the workshop showed sound levels from 86 to 90 dB(A) with some limited areas where they reached 95 dB(A). The risk for the employees was pointed out. In order to optimize the acoustic treatment and to limit the investment amount, a predictive acoustic survey was carried out. The mains results are recalled here. The initial spatial sound decay and sound levels where considered as reference data. The measured DL was below the required one and confirmed that it was possible to improve the acoustic performance of the workshop. A noise reduction operation was decided with the plant responsible. Several simulations where performed which included 1 : the treatment of the ceiling and the walls, 2 : A treatment limited to the ceiling for which, the simulated DL was 5,2 dB(A), much more than the required DL and the sound levels assessed by simulation where reduced from 3 to 6 dB(A). Finally, 570 absorbers (1200 x 600 x 40 mm) suspended to the ceiling where installed over 662 m² of the room, after which the spatial sound decay was significantly improved from 3,7 to 5,1 dB(A). The sound levels in the workshop where reduced to the range 80 - 87 dB(A) (92 dB(A) in very limited areas), but the daily exposure to noise of the employees was lower than 85 dB(A) due to their activity which implies many displacements along the bottling conveyor.

7 - SWIMMING POOL

The indoor swimming pool, located in the suburb of Paris, is composed of two swimming-bathes : 15 x 35m and 15 x 12m. The dimensions of the swimming hall are indicated on figure 5. The hall height is 8 to 9m . During the whole year, the swimming pool receives many schools. Swimmers are mainly from 7 to 11 years old. The swimming hall was very reverberant. The sound amplification due to the room characteristics was over 3 dB(A). Swimming instructors had complained of noisy environment. A noise survey has been carried out in order to assess the noise exposure of the swimming instructors and to define preventive means compatible with such an activity and wet environment. In these particular conditions, the noise exposure of the swimming instructors was difficult to assess, by reason of the sound sources which are unsteady and can strongly vary from one hour to another. This is why a measurement campaign was launched, the objective of which was to gather many data in order to get a daily noise exposure level as accurate as possible. The acoustic characterization of the room was obtained by measuring the reverberation time, because the room configuration was not compatible with the determination of the spatial sound decay.

The acoustic survey has been carried out as follow :

1 - Measurement of sound levels at different school periods and during summer an winter holidays.
2 - Acoustic characterization of the swimming hall by measuring the reverberation time (RT).
3 - Simulation of the swimming hall before any acoustic treatment with ambient noise measured in 1 - (actual conditions).
4 - Simulation of the room after applying horizontal absorbent panels to the ceiling part above the bathes ($\alpha_{SCEILING} = 0{,}8$).
5 - Assessment of the reverberation time after room acoustic treatment.

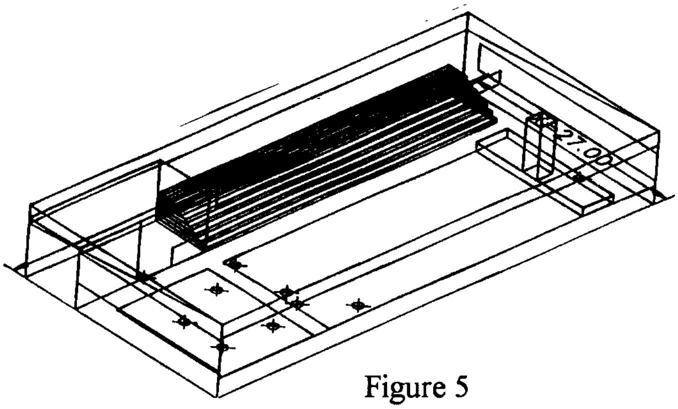


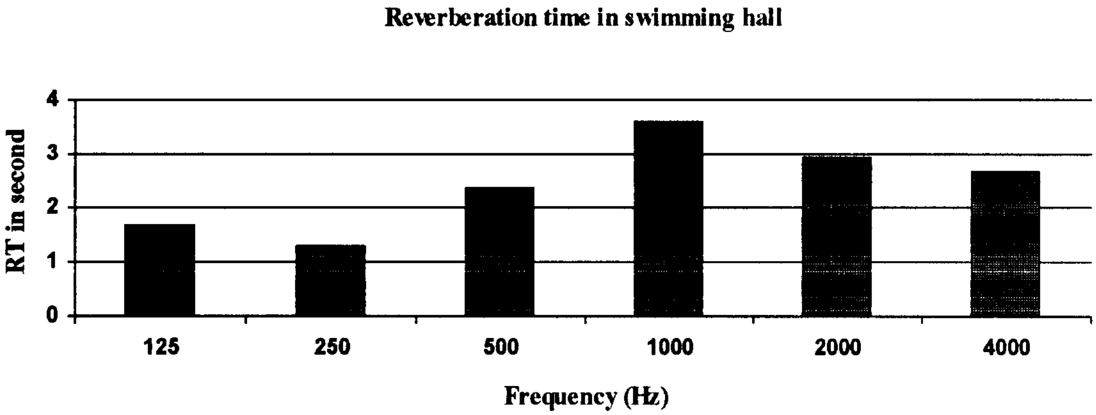
Figure 5

Daily noise level, swimming instructors were exposed to, are indicated in table 3.

October to March		April to September	
Noise exposure level during school period	Noise exposure level during holidays	Noise exposure level during school period	Noise exposure level during holidays
78 to 87 dB(A)	78 to 83 dB(A)	81 to 89 dB(A)	84 to 89 dB(A)

Table 3

The graph, hereafter, indicates the reverberation time, versus frequency, measured in the swimming hall before any acoustic modification.



The figure 6 represents the noise map resulting from the simulation of the swimming hall without any acoustic treatment. The figure 7 represents the noise map obtained in the same way, after covering the ceiling with horizontal panels having absorption coefficient of 0,8.

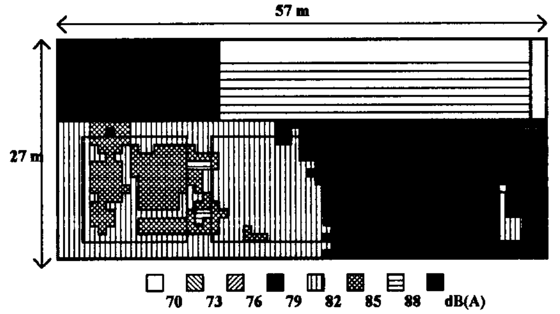


Figure 6 : initial sound levels

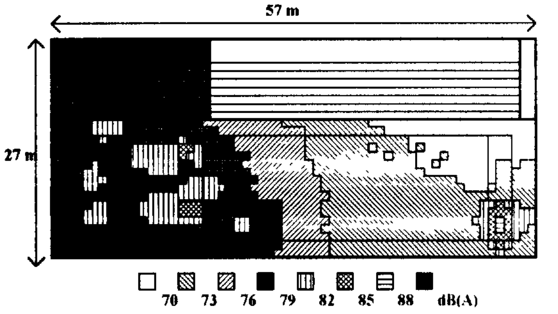


Figure 7 : final sound levels

Results analysis

The swimming instructors are exposed to sound levels which vary according to the hour, the day and the month. The assessment of the noise exposure in such conditions implied several measurements in the swimming hall in order to get representative samples of the different exposure conditions. During winter holidays, the noise exposure levels were in the range 78 to 83 dB(A), but during summer holidays, they were in the range 84 to 89 dB(A). The noise sources were mainly located in the smallest swimming-bath where many children use to play. The reverberation time was 3,6 seconds in the 1000 Hz band, when regulation stipulates that it must be less than 2,3 seconds. On figure 7, the noise map point out a significant noise abatement compared to the initial situation. (3 to 6 dB(A)). The reverberation time in the 1000 Hz band should be reduced to 1,2 second and the noise exposure level of the swimming instructors should be reduced to the range 75 to 86 dB(A).

8 - CONCLUSIONS

The predictive acoustic software RAYSCAD+ is helpful to assess noise exposure levels at the workplaces by simulating modifications of parameters which have effect on the ambient noise of rooms such as wall absorption properties, machine fittings... . Several solutions can be easily implemented and results can be compared to the required objectives. It is possible to optimize the room treatment and then to reduce the investment amount. Sometimes, it appears that modifications which are limited to the absorption properties of the walls do not give a significant noise abatement and have to be carried out in conjunction with complementary arrangements. Moving a machine to another room, moving employees away from the noise sources when it is possible, can improve the situation. So, the managers can choose the best solution which matches with the expected noise reduction. The three actual cases presented in the present document were also used to evaluate the simulation software in the field and to compare the theoretical and actual results. The results quality depends on the accuracy of the parameters which define the acoustic environment. It depends also, on the very first simulation performed with all the initial conditions the purpose of which being to get results which match with the initial measurements. All these conditions being satisfied, the final noise reduction assessment is often realistic as it was pointed out.

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