Acoustic levels in the manufacture of wood chairs

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Abstract
The legislative decree 195/2006 has implemented the European Directive 2003/10/CE about noise exposure of workers and it has introduced a series of articles defining health and safety standards. The sector of wood processing is one of the most concerned by such a problem; in particular, the highest number of recognized cases of hypoacusia and deafness occur in furniture factories. As a result, a study was carried out on the acoustic levels in some Calabrian secondary wood industries manufacturing predominantly chairs, but also tables and other wood furniture. The acoustic survey was carried out under full and normal operating conditions of the industries; after evaluating the residence times of workers in their work station, the level of daily personal exposure was estimated. The examined industries do not always comply with the ergonomics and safety standards established by law for an acoustic comfort meeting workers' needs. Such interventions take into account the change of the lay-out of the production cycle, the reduction of acoustic emissions directly at their sources, an effective organization of work and a greater awareness towards the use of personal protection devices.

Keywords: acoustic pollution, noise reduction, safety, wood processing.

Introduction

The Calabrian forest resources play a role of primary importance for the regional economy; Calabria is, in fact, one of the first regions in Italy for its forest surface, its woodland index and its yearly wood manufacture. The quantity of timber processed every year is 10% of the whole Italian sector of wood transformation. The wood transformation industries which have been involved survive thanks to their flexibility and adaptability. In particular, these industries keep on covering special niches in the marketplace, such as furniture industries and hand-made carpentry, where quality productions and order productions are very important (Zimbalatti *et al.*, 2005). In Calabria the wood industry, furniture included, takes up over 20.000 workers (Istat, 2001). In particular, the furniture manufacture in Calabria reaches a point of excellence in the area of Serrastretta, a village known as 'The city of the chair', which boasts a consolidated tradition for the manufacture of chairs and other items. In this mountain centre there are several small and medium size factories, that follow an important hand-crafted tradition, and with their very valuable products they manage to keep significant market shares, in spite of the keen competition of the sector. On the technical level, the cycle of the factories manufacture, which gets inspiration from the hand-crafted tradition, is today nearly wholly mechanized. The good levels of productivity achieved, must not allow to under estimate the risks for the health of the workers who work in these factories. In particular, the process of mechanization of the manufacture processes has led to an increase of the noise sources and, as a result, of an increase of the percentage of workers exposed to this risk. Not by chance, in the wood macrosector, the majority of recognized cases of hypacusia and deafness take place in furniture factories; still, the index of frequency is not particularly high (Verdel *et al.*, 2001).

Materials and methods

The sector of wood transformation is traditionally marked by high levels of exposure to noise, due to a series of attendant circumstances, such as the use of facilities with high acoustic power in often narrow work environments (Piccioni R., 2006). Starting from these considerations, the Mechanical Section of the D*i*STA*f*A of the Mediterranean University of Reggio Calabria, which has been interested in research themes about safety at work for years, has carried out a survey about acoustic levels in some secondary wood industries manufacturing chairs, tables and other wood furniture items.

The legislation reference

The legislation about noise pollution has been recently changed. The D. Lgs. 195/2006, in fact, has changed the D. Lgs. 626/94. The title has been replaced by the Title V-bis, which regards the rules for the accomplishment of the "Protection from Physical Agents" at work. In particular, it has received and accomplished the European Directive 2003/10/CE on the workers' exposure to noise, and it has introduced a series of articles which define the minimum requirements for health and safety with regard to exposure to noise. First of all, the limit of daily exposition to noise decreases from 90 to 87 dB(A); this limit considers also the noise reduction produced by the personal protective equipment (PPE) worn by workers. Moreover, the peak level of impulsive noise is measured by the weight curve C, instead of the linear system. The maximum value of exposure to noise beyond whom it is obligatory to signal and/or to define the borders of the area, decreases from 90 to 85 dB(A); finally, the evaluation of noise considers also the possible interactions with vibrations or hearing toxic substances (Casini S., 2006). The new legislation defines, coherently with what said before, two values of reference: the **maximum value of exposure**, that is the level it is not possible to exceed, and the **action values**, lower and higher, that have to be considered by the employer to take specific protection measures for workers; in particular, if the lower value is exceeded, activities of "information, formation and PPE supply" must be carried out; if the higher value is exceeded, actions of "information, training and PPE supply with the obligation of use" are needed (Table 1).

Instrumentation and test parameters

The researches have been carried out with the use of a precision integrator phonometer Delta Ohm HD 9020. This instrument is set every year at the laboratory S.I.T.; before and after each daily series of measurements, the calibration has been controlled by a calibrator Delta Ohm HD 9101. The collected data have been transferred through a serial cable to a laptop to be processed successively. The modalities of measurement and the methodology of research include the arrangement of the instrument, through a special tripod and a bracket with a feeler, at the height of the operator's ear, and at such a distance from his head, so as to reduce, as much as possible, the effects of diffraction and the distance of the measured value. The tests, have been carried out during full activity and normal operating conditions of the industries and, after evaluating the workers' residence time in their work stations, the level of daily personal exposure has been calculated ($L_{EX, 8h}$).

The knowledge for each worker of the level of exposure and the value of peak acoustic pressure makes possible to verify the respect of the limit values established in the art. 49-quater of D.Lgs. 195/06, to decide the prevention and protection measures to be taken. Moreover, it is very useful to estimate also the uncertainty related to the level of daily personal exposure, to define if a specific limit of exposure is, or can be exceeded.

Level of daily personal exposure = $L_{EX,8h} = L_{Aeq,Te} + 10 \log \left(\frac{T_e}{T_0}\right)$ (dB(A))

where: $L_{Aeq,Te} = 10 \log \left\{\frac{1}{Te} \int_0^{T_e} \left[\frac{P_A(t)}{P_0}\right]^2 dt\right\}$ (1)

T_e = daily period of a worker's personal exposure to noise;
T_o = 8 hours;
P_A = instantaneous acoustic pressure (weighting scale A), in Pa;
P_0 = 20 μPa.

Table 1. Main differences between the old and the new legislation

Estimated provisions	D.Lgs. 277/1991	D.Lgs. 195/2006
Periodicity for noise evaluation	No	4 years
Interaction with vibrations and hearing toxic substances	No	Yes
Areas to be signaled/boundaries to be defined	≥ 90 dB(A)	≥ 85 dB(A)
Measure of peak level	dB(lin)	dB(C)
Lower value of action	85 dB(A)	80 dB(A)
Higher value of action	90 dB(A)	85 dB(A)
Maximum limit of exposure	90 dB(A)	87 dB(A)
Training for the use of PPE	≥ 85 dB(A)	≥ 80 dB(A)
Register of statements	Yes	No

Reduction of personal protective equipment

The new legislation imposes the employer, in case of exposure beyond the maximum value of 87 dB(A), to check the efficiency of the devices of hearing individual protection. So, during the tests in the different factories, the indications given by the D.M. 02/05/01 which fix the standards for the identification and the use of hearing protection devices through the reception of the rule UNI-EN 458 (Table 2), have been applied.

The action level (L_{act} - 85 dB) is the value beyond whom the employer make sure all workers wear PPE when noise levels are over 85 dB(A). In case the valuation points out an insufficient protection, it is necessary to use another kind of hearing protector with a higher reduction. On the contrary, if the valuation reveals that the protection effect is too high, it is necessary to use a different PPE with a lower reduction: we know indeed that hyperprotection can cause feelings of isolation and difficulty to perceive sounds. So it is necessary to make sure that the protection offered by the PPE stays in the limits of acceptance according to table 2. To verify the suitability of a PPE there are several methods based on the level of knowledge of the peculiarities of the environment noise and the values of acoustic reduction provided by the constructor of the device, together with the mark CE.

The method used in this research for the evaluation of the efficiency of PPE, is the system of simplified reduction of noise level - SNR (Simplified Noise Reduction) - that uses the equivalent level of acoustic noise pressure according to curve C. Successively, the equivalent

level for each worn device (L'_{Aeq}) has been compared to the action level to evaluate the suitability of the hearing protector itself.

Real level at the ear = $L'_{Aeq} = L_{Ceq} - SNR$ (2)

where:
L_{Ceq} = Equivalent level of acoustic noise pressure according to weighting scale C;
SNR = Value of acoustic reduction per octave band of a hearing protector.

Table 2. Evaluation of acoustic reduction

Real level at the ear	L'_{Aeq} dB	Evaluation of protection
Higher than L_{act}	80	Insufficient
Between L_{act} and L_{act} - 5	80 - 75	Acceptable
Between L_{act} - 5 and L_{act} - 10	75 - 70	Good
Between L_{act} - 10 and L_{act} - 15	70 - 65	Acceptable
Lower than L_{act} - 15	65	Too high (*Hyperprotection*)

Examined factories and production cycles

In the geographical area interested by this research there are today about thirty small enterprises, which produce in the average 70.000 chairs a year with a consolidated tradition, that comes from the use of wood of the renowned "Faggeta di Serrastretta".

The tests have been carried out in three factories ("A", "B", "C"), specialized in the manufacture of chairs, tables and other wood items (Table 3). In these factories, that are representative of the whole production area, the cycle is nearly fully mechanized; the work lines are composed of different kinds of machines. The work cycle can start from both sawed and unfinished products. In any case, the work diagram is articulated as follows:

- **Transverse sawing:** this operation, which is carried out by the band saw, enable to make useful pieces for the furniture manufacture from sawed products.
- **Shaping/planing:** the pieces coming from the sawing are subjected to the shaping or the planing. In particular, wood pieces are given a form or a non-rectilinear contour by the shaping. On the contrary, by the planning, pieces are given the wanted dimensions and smoothing. Shaping is made by two kinds of machines: la slides compound saw and the vertical axle moulder (*toupie*). For linear pieces the shaping is made by the planer.
- **Sanding**: Shaped wood pieces are smoothed. This operation is made by orbital sanders and band sanders.
- **Drilling**: shaped and smoothed pieces are joined together by the tenone joint and the mortase. The joint is a slot of wood pieces with prominences and pieces with complementary creaks. Prominences are called tenones, creaks are named mortases. Mortases are made by the mortising machine; tenones are carried out by the tenoning machine. Moreover, tenones are subjected to the knurling, which imprints on them splines that support the successive glueing operation. This operation is made by the knurling machine. The screws holes are made by drilling machines.

- **Frame assembly**: the furniture frame is made by joining wood pieces manually by the tenone joint and the mortase. With regard to chairs, the operators put the frame on the narrow passage, a facility that makes a pressure on specific parts of the manufactured item to make it steady.

Table 3. Peculiarities of the examined factories

Peculiarities	Factory		
	A	B	C
Number workers	6	6	5
Yearly production			
• chairs	25.000	12.000	20.000
• tables	5.000	3.000	1.000
• benches	-	1.000	-
• stools	-	4.000	-
Surface factory (m^2)	1.100	2.000	800

Results

In tables 4, 5 and 6 you can see the results of measurements and the processing activities carried out in each factory in the different work stations. The machines working wood through the shaving removal by tools, disks or rolling knives at a high speed, give out high acoustic levels, especially if they are not well used and repaired. In no station the value of L_{peak}(C) came out higher or equal to135 db(C), so the verification of the respect of the action values and the exposure limits has been carried out exclusively on the base of the values of the daily personal exposure $L_{EX,8h}$.

In particular, in the machines for the drilling and the sanding, in the three factories, the equivalent levels are equal and sometimes higher to 85dB(A). As a result, the values of the daily personal exposure in a period of eight hours are different in the three examined factories. Indeed, for the 47% of the 17 examined workers the maximum exposure value of 87dB(A) is exceeded, and the choice of PPE does not seem to be satisfying (Figure 1).

In factory A, lower action values, 80 dB(A), have been exceeded in all work stations leading the worker to supply protection devices. In particular, five workers are subjected to acoustic levels higher than 85 dB(A), high action value which, not only forces workers to wear PPE, but also imposes the employer to create and apply a specific programme of technical and organizing measures to reduce this exposure. All workers have been provided with auricular insets with an arc of 3M model 1310, certificated according the norm EN 352-2. The test of the reduction produced by these PPE shows as the use of insets is excessive for the operator 1, insufficient for the employer A6, while it is acceptable for all other workers. The acoustic values given out from the mortising machine are outlined. They are the highest of the whole factory because of the old age of the machine, the bad conditions of maintenance and his closeness to walls (Figure 2). The factory, therefore, does not comply with the minimum requirements for an acoustic comfort; the overcoming of limit values found in all machines must induce the employer to reconsider the factory layout, its management and maintenance, and incidentally think about the replacement of some machines (ex. the mortising machine).

In B, acoustic levels do not exceed 80 dB(A), except the tenoning machine which reaches 95 dB(A). This factory has clearly better acoustic conditions compared to the

previous one; in fact, only one person works in conditions that exceed the legal limit value (Figure 2). The factory has only one machine which exceeds the limits fixed by law; so it could be separated from the other machines by plastic vertical strips (Windor Strips), already applied with success in bottling factories (Febo e Orlando, 2002). The low cost, the facility of maintenance and the good functionality make it an applicable solution compared to more complex reorganization interventions. Anyway, the noticed exceeding value would demand the creation of an access limited area defining its borders and limiting the access only to workers with appropriate individual protection devices. The values of daily personal exposure, according to what has been said, are, except operator B5, lower than legal values both for the excellent machines arrangement and their conditions of technical efficiency. The reduction produced by earphones - 3 M 1435 - in favour of the two workers (B5-B6), subjected respectively to values higher than 90 and 80 db(A), is acceptable.

The data collected in enterprise C show quite different acoustic levels (Figure 2); there are machines with values higher than 87 dB(A), in comparison with other machines which have values around 80 dB(A). In particular, high levels have been registered near the planer (97,7 dB(A)) and the unframing machine (95,9 dB(A)). Other machines with high acoustic levels, according to the present legislation, are the tenoning machine, with 89,1 dB(A), and the mortising machine with 86,4 dB(A). Inside this factory, workers change their task every two hours; by this choice, the employer means to guarantee a complete shift rotation of work burdens; this situation affects, therefore, the levels of personal exposure to noise, as well. This management of work tasks exposes all workers to acoustic levels, which are always higher than the maximum exposure limit, and obliges them, in the same way, to the use of PPE, that are however appropriate to reduce these levels. Indeed, the choice of the earphone (Twin Mark 12), used by this factory, appears to have good reducing levels. It could be useful, in addition, to isolate acoustically the machines with higher emission levels. It would be also necessary to draw attention on the work areas where this machines work, as they exceed of 10 dB the medium values, to warn the operator about the importance of using PPE.

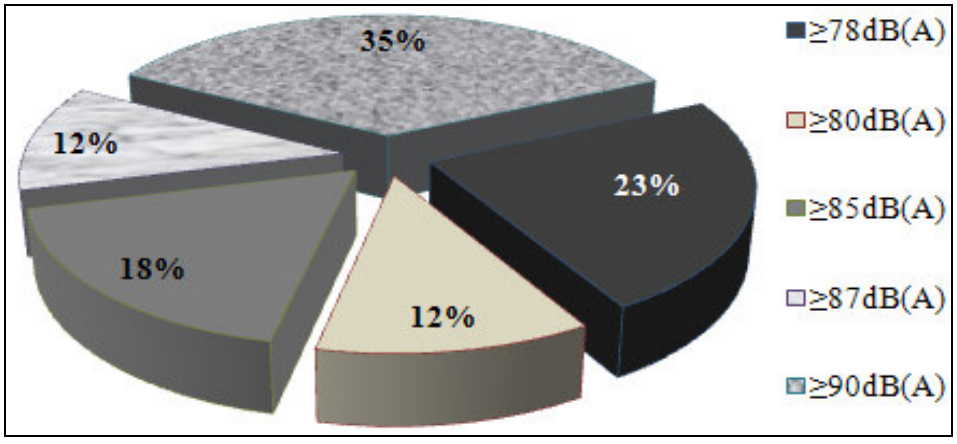

Figure 1. Distribution of workers according to personal exposure

Table 4. Acoustic levels in factory A

Work station	$L_{eq,i}$ (ε)	L_{peak} (dB)	Operator				
			A1	A2 – A3	A4	A5	A6
			Residence time t_i (hours)				
1. Band saw	86,5 (± 0,4)	112,4		8,00			
2. Trimmer	88,9 (± 0,6)	113,7				4,00	
3. Unframing machine	77,2 (± 0,6)	108,3	4,00				
4. Toupie	83,3 (± 0,4)	111,7	4,00				
5. Planer	86,2 (± 0,1)	113,5			4,00		
6. Sander	85,2 (± 0,1)	112,9			4,00		
7. Tenoning machine	84,4 (± 0,3)	110,8				4,00	4,00
8. Mortising machine	103,8 (± 0,3)	139,1					4,00
$L_{EX,8h}$ [dB(A)]			**81,2**	**86,5**	**85,7**	**87,2**	**100,8**
ε $L_{EX,8h}$ [dB(A)]			± 0,8	± 0,8	± 0,7	± 0,9	± 0,8
Level of exposure with PPE			62,0	68,0	67,0	68,0	82,0
Reduction			Too high	Acceptable	Acceptable	Acceptable	Insufficient

Table 5. Acoustic levels in factory B

Work station	$L_{eq,i}$ (ε)	L_{peak} (dB)	Operator				
			B1	B2 – B3	B4	B5	B6
			Residence time t_i (hours)				
1. Band saw	78,3 (± 0,3)	106,5		5,00			
2. Alternate saw	80,0 (± 0,9)	107,9				4,00	
3. Unframing machine	79,3 (± 0,5)	108,1			8,00		
4. Toupie	77,2 (± 0,4)	106,9	2,00	3,00			
5. Planer	80,3 (± 0,4)	111,4	6,00				
6. Sanding	79,8 (± 0,1)	111,1					4,00
7. Tenoning machine	95,0 (± 0,2)	119,8				4,00	
8. Mortising machine	80,5 (± 0,5)	109,1					4,00
$L_{EX,8h}$ [dB(A)]			**79,7**	**77,9**	**79,3**	**92,1**	**80,2**
ε $L_{EX,8h}$ [dB(A)]			± 0,8	± 0,8	± 0,9	± 0,7	± 0,8
Level of exposure with PPE						77,0	66,0
Reduction						Acceptable	Acceptable

Table 6. Acoustic levels in factory C

Work station	$L_{eq,i}$ (ε)	L_{peak} (dB)	Operator				
			C1	C2	C3	C4	C5
			Residence time t_i (hours)				
1. Band saw	81,3 (± 0,6)	109,8	2,00	2,00			
2. Unframing machine	95,9 (± 1,4)	120,9		2,00	2,00	2,00	
3. Toupie	80,3 (± 0,6)	109,5	2,00			2,00	
4. Planer	97,7 (± 0,5)	122,4	2,00				2,00
5. Sander I	80,4 (± 0,2)	108,7			2,00		
6. Sander II	77,7 (± 0,3)	106,5		2,00		2,00	4,00
7. Tenoning machine	89,1 (± 0,6)	118,5			2,00	2,00	2,00
8. Mortising machine	86,4 (± 0,4)	115,9	2,00	2,00	2,00		
$L_{EX,8h}$ [dB(A)]			**88,0**	**90,5**	**91,2**	**90,9**	**92,4**
ε $L_{EX,8h}$ [dB(A)]			± 0,9	± 1,6	± 1,5	± 1,5	± 0,9
Level of exposure with PPE			70,0	73,0	73,0	73,0	74,0
Reduction			Acceptable	Good	Good	Good	Good

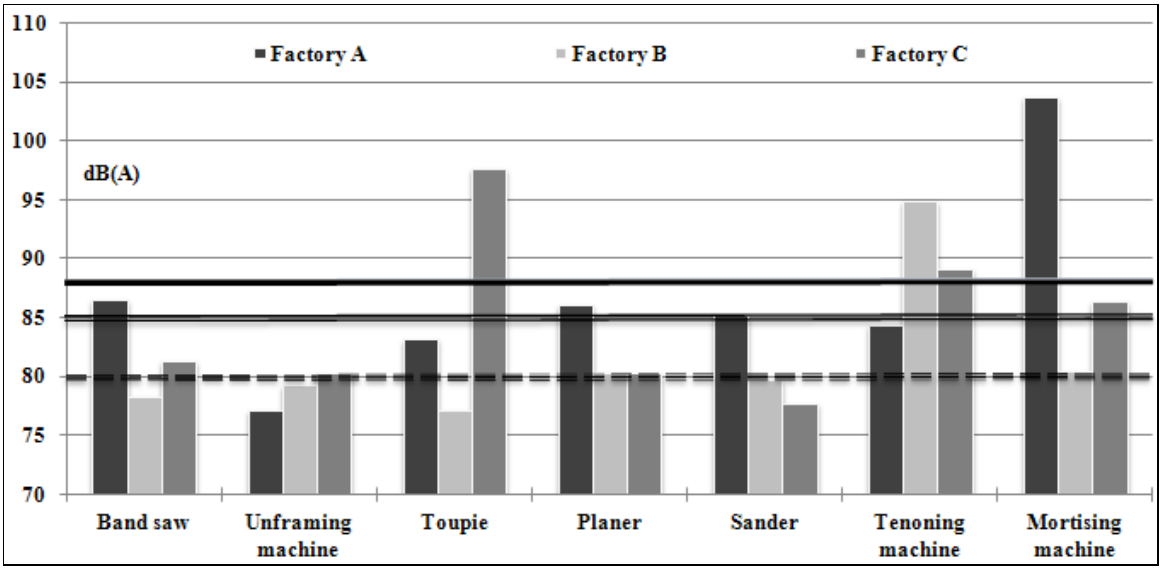

Figure 2. Equivalent levels in the examined machines

Conclusions

The phonometric data processing has enabled to outline a general picture, even though approximate, of the acoustic conditions of the three considered factories, with reference to the monitored mountain areas. Unfortunately, it has turned out that the non-reception and non-application of the present legislation endangers the safety of workers, who, in most cases, are unaware of the risks they run. In the work stations where there is an equivalent acoustic level higher than 85 dB(A), it would be important to adopt specific balancing measures or precautionary interventions, and limit the access only to the employers with appropriate personal protective equipment, as well (earphones or auricular insets).

The noise reduction, at the source or on the run, should be one of the main management programmes of this risk factor. This activity must take into account both the facilities and planning, as well as maintenance to control acoustic pollution inside factories during the cycle of wood processing. The clearing of work stations can be positively carried out by limiting the productive lines in soundproofing cabins and tunnels, and coating the plates subjected to impacts (Bianconi A., 2004). With regard to work places, there is in all three factories, a complete saturation of spaces. The acoustic field is the sum of the direct field and the one reflected by walls. To eliminate the latter, it is reasonable to put appropriate soundproofing panels hanging from the roof and applied to the factory walls. In general, the visited enterprises rely on the supply to workers of the different kinds of PPE hearing protectors in commerce for the protection from noise. But with regard to legislation, it is important to remember that no auricular protection is valid everywhere. It is necessary to know the peculiarities of noise in the different environments where people work, to choose the right acoustic damping factor. It is also important to consider the length of stays in particularly noisy environments. In some cases, if hearing is not constantly protected, it risks permanent damages.

References

Bianconi A., 2004. Valutazione all'esposizione a rumore e vibrazioni in alcune PMI umbre operanti nel settore legno. 3° Seminario dei professionisti CONTARP "La prevenzione che cambia. I ruoli, le strategie e le sinergie degli "attori" coinvolti".

Caporale R., Bisceglia M., 2003. Le Ipoacusie da rumore in ambito INAIL: aspetti medico-legali. Sovrintendenza Medica Generale INAIL.

Casini S., 2006. Da dicembre meno rumore in azienda. Dati Inail sull'andamento degli infortuni sul lavoro, n°12.

Cassano F., Bavaro P., Aloise I., Dal Sasso P., Ruggiero G., 2005. Problematiche connesse all'inquinamento da polveri e da rumore in un opificio per la lavorazione delle mandorle. Atti del Convegno AIIA "L'ingegneria agraria per lo sviluppo sostenibile dell'area mediterranea", Catania 27-30 giugno.

Decreto Legislativo del 10 aprile 2006, n. 195 Attuazione della direttiva 2003/10/CE relativa all'esposizione dei lavoratori ai rischi derivanti dagli agenti fisici (rumore).

Febo P., Orlando S., 2001. Interventi per ridurre la rumorosità all'orecchio degli operatori di una cantina con due linee di imbottigliamento. Rivista di Ingegneria Agraria, n°4, 244±252.

Giametta F., Proto A.R., Zimbalatti G., 2007. Analisi dell'esposizione al rumore nelle industrie di prima trasformazione del legno in Calabria, Sherwood – Foreste ed Alberi Oggi n°129, - Mensile di divulgazione tecnico-scientifica della Compagnia delle Foreste.

Piccioni R., 2006. Bonifica acustica nelle aziende di trasformazione del legno. Dati Inail sull'andamento degli infortuni sul lavoro, n°11.

Verdel U., Iotti A., Piccioni R., 2001. Danni professionali da rumore e vibrazioni nel periodo 1989-1999. Atti del seminario nazionale "Linee guida ISPESL sull'esposizione professionale a rumore e vibrazioni Roma, 30 gennaio.

Zimbalatti G., Proto A.R., Abenavoli L.M., 2005. Impianti e cicli produttivi in segherie calabresi. Atti del Convegno AIIA "L'ingegneria agraria per lo sviluppo sostenibile dell'area mediterranea", Catania 27-30 giugno.

Zimbalatti G., Zema D., 1999. Research into environmental noise in continuous cycle oil mills. Proceedings of XXVIII CIOSTA-CIGR V Congress, Horsens, Denmark, 14-17 giugno, 244±249.

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