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Control of the workplace environment by physical factors and SMART monitoring

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ABSTRACT

Purpose: To develop and implementation in practice an algorithm for smart monitoring of workplace environmental physical factors for occupational health and safety (OSH) management.

Design/methodology/approach: A brief conceptual analysis of existing approaches to workplace environmental physical factors monitoring was conducted and reasonably suggest a decision-making algorithm to reduce the negative impact of this factors as an element of the OSH management system.

Findings: An algorithm has been developed that provides continual improvement of the OSH management system to improve overall labour productivity and which has 3 key positive features: (1) improved data collection, (2) improved data transfer and (3) operational determination of the working conditions class.

Research limitations/implications: The implementation of the proposed algorithm for substantiating managerial decisions to reduce the negative impact of workplace physical factors is shown by the example of four workplace environmental physical factors in the products manufacture from glass.

Practical implications: If management decisions on the implementation of protective measures are taken in accordance with the proposed monitoring algorithm, these decisions will be timely and justified. This makes it possible to reduce the time of the dangerous effects of physical factors on the health of workers and reduce the level of these factors to improve working conditions. That is, an algorithm is proposed that provides continuous improvement of the OSH management system to increase overall labour productivity.

Originality/value: Current monitoring of workplace environmental physical factors values are carried out in accordance with the justified monitoring intervals for each factor that provides the necessary and sufficient amount of data and eliminates the transfer of useless data.

Keywords: Environmental physical factors, Occupational health, Monitoring, Occupational safety and health management system, Decision-making algorithm

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MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

According to world health organization, a healthy workplace is one in which workers and managers collaborate to use a continual improvement process to protect and promote the health, safety and well-being of workers and the sustainability of the workplace. This takes into account identified needs such as health and safety concerns in the physical work environment; health, safety and well-being concerns in the psychosocial work environment including organization of work and workplace culture; personal health resources in the workplace; and ways of participating in the community to improve the health of workers, their families and other members of the community [1]. In 2018, International Labour Organization (ILO) estimates, every year industrial accidents and occupational diseases that claim the lives of 2.3 million workers worldwide. Another 160 million workers suffer from occupational diseases each year, and 313 million from non-fatal accidents [2]. This entails serious costs for enterprises and the economy as a whole [3]. Industrial accidents victims and occupational diseases are especially numerous in developing countries [4-8], where huge people masses work in enterprises with dangerous and harmful working conditions, including in agriculture [9,10], chemical [11-14], mining industry [15,16] etc. Death and injury as a result of harmful and dangerous activities are one of the main poverty causes, which undermine the families' well-being [3,17]. Occupational safety and health (OSH) management system is aimed at identifying key challenges in the existing OSH management system and main directions and ways of addressing them to enhance its performance, shaping a modern safe and healthy working environment, minimizing socio-economic consequences of adverse impacts upon human health and working capacity during labour activities, and establishing a national preventative OSH culture.

Currently, the main assessing occupational risk method is working conditions certification of workplace, with which the work environment conformity with its normative characteristics according to individual risk factors is established. Such certification does not have other useful features, since it does not allow evaluating the complex and operational combination of the effects of all risk factors on the employee health. Therefore, the results of certification should be supported by a comprehensive assessment of the cumulative effect of all workplace environment factors and the labour process on the employee health [18,19].

A comprehensive assessment of the all workplace environmental factors influence implies the presence of specialists in production workshops who are not associated with the manufacturing process. Since a large number of measurements should be made for each harmful or dangerous factor, the long-term presence of an external specialist contributes to some inconvenience for production workers. If the measurements are not enough, then the result of a comprehensive assessment may not be correct. Thus, workplace environmental factors monitoring, namely, the number of measurements should be minimal, but sufficient to draw the right conclusions about risk factors at a particular workplace.

As demand for glass and glass products is currently increasing, in recent years there has been an expansion in the production of glass products. Experts found that when performing certain types of work in the glass production process, occupational diseases develop in workers. The reason for this is the action of hazardous and harmful substances and physical factors of the working environment (dust, noise, vibration, adverse microclimate, etc.). Therefore, namely this production process was chosen for the study, which is presented in this work.

On the example of the workshop for the transportation, preparation and mixing of materials in the glass products manufacture, it was established and mathematically justified that the workplace environmental factors values which are dangerous and harmful for workers' health can significantly change even with unchanged technological processes [20]. This is associated with the features of technological processes of a particular production and means that different environmental factors have different durations of the stationary period (that is the period during which the dynamics of harmful factors values is stationary) and, therefore, during certification, their values must be measured with different monitoring intervals. The authors of the study [20] substantiated that in order to improve the organization of monitoring and occupational risk managing; it is advisable to adopt a discretization step that is equal to the largest integer that satisfies the condition:

$$\overline{\Delta}_K \leq 0.3 \cdot T , \qquad (1)$$

where $\overline{\Delta}_K$ is monitoring interval, which corresponds to the most unfavourable dynamics of dangerous and harmful environmental factors and T is stationary period duration.

If this condition is met, then with probability P = 0.95, all possible emissions of values (that is, values that exceed the normalized value) will be recorded.

The main workplace environmental factors which are dangerous and harmful for workers' health, the effects of which can cause occupational disease in the workers of the transportation, preparation and mixing materials workshop in the glass products manufacture, are prolonged inhalation of dust, the increased noise, vibration, and an unfavourable microclimate (Tab. 1).

Therefore, for such workplace environmental physical factors as noise, vibration, dust, and relative humidity, in the study [22], mathematical modelling and prediction of their values during a work shift were carried out. The obtained mathematical models make it possible to adequately assess the danger to the health of an employee, substantiate measures to improve working conditions and predict the results of the implementation of planned protective measures.

This study consists in assessing working conditions in the manufacture of glass products according to the degree of harmfulness and danger. Moreover, the assessment is based on monitoring the physical environmental factors values at the workplace in accordance with mathematically sound control intervals.

Thus, the purpose of this study is to develop and implementation in practice an algorithm for smart monitoring of workplace environmental physical factors for OSH management.

2. Materials and methods

A brief conceptual analysis of existing approaches to workplace environmental physical factors monitoring was conducted and reasonably suggest a decision-making algorithm to reduce the negative impact of this factors as an element of the OSH management system.

Experimental measurements of the harmful and hazardous factors values at workplace were carried out using special certified instruments at workplaces in the workshop for the transportation, preparation and mixing of materials in the glass products manufacture. Noise, air dustiness of the production environment, vibration and humidity were measured in accordance with the methodology presented in the previous study [20]. For each harmful factor, 200 measurements were made.

Benetech GM1358 (SR5814) high-precision digital sound level meter (± 1.5 dB) was used to measure the noise level (working range from 30 to 130 dB). Dustiness was measured by specialists of the certified laboratory. Relative humidity was measured with a high-precision professional Xintest "HT-350" thermohygrometer (temperature range from -30.0 to + 100.0°C, humidity range from 0 to 100% RH). The PCE-VM 40C vibrometer was used to measure the vibration level (complies with DIN 4150-3, BS 7385).

Table 1.
Name of occupational diseases that can be caused under the influence occupational environmental factors (WHO 2016) at glass products production [21]

Disease name	**Code ICD-10 [21]**	**Hazardous and harmful substances and occupational factors, the effects of which can cause occupational disease**
Diseases caused by exposure to industrial aerosols		
Pneumoconiosis: silicosis, silicatosis, metalloconiosis, etc.	J60-J64	Prolonged inhalation of dust containing silicon dioxide in a free or combined state, dust containing carbon (coal, coke, soot, graphite, diamond) dust of metals and their oxides, mixed types of dust
Konyo tuberculosis (pneumoconiosis associated with tuberculosis)	J65	Prolonged inhalation of dust containing free or coupled silica, carbon dust; dust of metals and their oxides, mixed types of dust
Chronic rhino pharyngolaryngitis	J68.2	Prolonged inhalation of dust various types
Diseases caused by the physical factors action		
Overheating: acute (heat and sun stroke, thermal fainting, heat cramps, etc.)	T67	Heating microclimate and intense radiation in the production environment

The workshop choice is justified by the results of the employees' survey and expert evaluation of specialists (the strict ranking method was used). According to these results, the workshop for the transportation, preparation and mixing of materials in the glass products manufacture is defined as the workshop with the most harmful working conditions at the enterprise.

3. Results

3.1. An algorithm for substantiating managerial decisions to reduce the negative impact of workplace physical factors

Industrial safety in modern conditions is provided only if:

- The continuous assessment and smart (and effective) monitoring of occupational risks was carried out;
- The timely development of management decisions and the adoption of necessary protective measures on the basis on reliable information were carried out;
- The timely and complete information about the control object was received.

The main requirement for the OSH management system development built using modern information technologies is the necessary information incompleteness elimination. The main core of an effective OSH management system is smart monitoring of environmental factors at the workplace.

The main purpose of smart monitoring of harmful and hazardous physical environmental factors is to ensure systematic control of the observation results, coordination of activities aimed at creating safe and harmless working conditions based on the integrated use of technical, software and methodological support. Such monitoring helps to obtain information about the presence (or absence) of danger at the workplace and to make informed operational decisions on OSH managing. In this regard, the approach to the development of the algorithm included the sequential execution of several stages (Fig. 1).

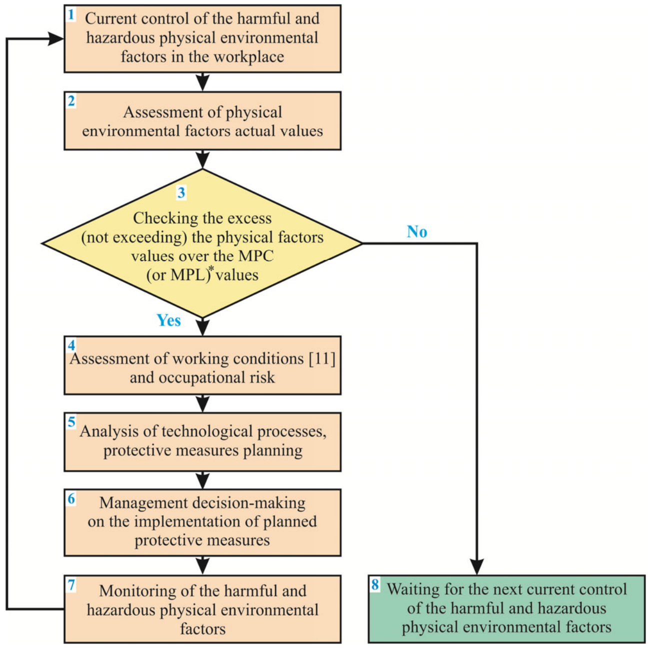

Fig. 1. Algorithm for making justified decisions to reduce the negative impact of the hazardous and harmful physical factors at the workplace (*MPC is maximum permissible concentration; MPL is maximum permissible level)

Table 2.
The obtained values of the stationary period and monitoring intervals [20]

No.	Workplace environmental physical factors names	Stationary period, min	Monitoring interval, min
1	Noise	28	9
2	Vibration	20	7
3	Air dustiness	9	3
4	Relative humidity	66	22

Step 1 – Current control of the harmful and hazardous physical environmental factors in the workplace

This control provides for the rapid collection of data in accordance with the established monitoring intervals for each factor, which are shown in the Table 2 [20].

The prompt receipt of reliable information is largely carried out by the bandwidth of communication channels. There are data transmission systems based on the principle of fixed distribution of channel capacity and adaptive systems [23]. Given the features of the collection, transmission and processing of data that characterize the controlled parameters, the use of adaptive systems is advisable. The set of data that comes from sensors to control the environmental physical factors can be considered as a set of random processes [23]. Based on the task and on the basis of the research, a generalized structure of a system for monitoring hazardous and harmful physical factors in the working environment has been developed (Fig. 2).

In this system: S_1, …, S_n are sensors of controlled parameters (primary meters of workplace environmental physical factors); C_1, …, C_n are analogy-frequency converters; data processing centre is a hardware and software computing complex that includes: server, one or more automated workstations based on personal computers, and peripheral equipment. The Centre is intended for the following main tasks:

- The workplace environmental physical factors monitoring system administration and configuration;
- The received data collection and accumulation;
- Data processing (visualization, reporting, verification, analysis, modelling, etc.);
- Information interaction with other systems;
- Ensuring information of the security and data integrity.

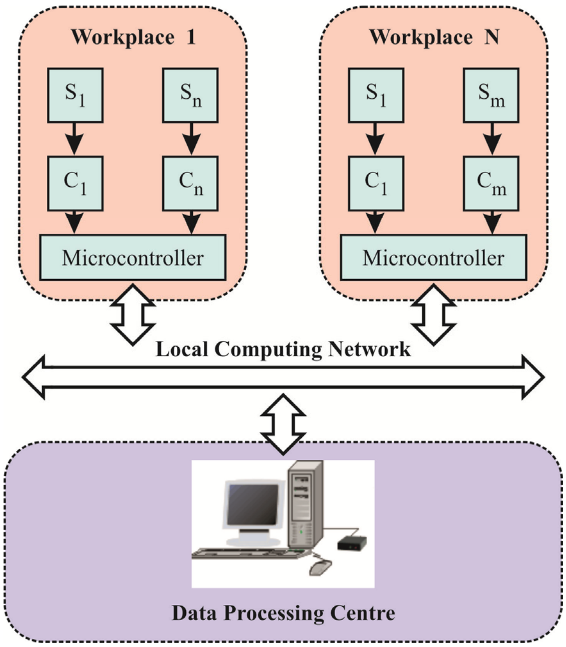

Fig. 2. Generalized structure of the monitoring system of hazardous and harmful physical factors in the working environment

Primary data collection devices include: noise, vibration, dust, light, and microclimate, infrared and electromagnetic parameters. These meters should be sufficiently sensitive in all ranges of measured factors, and should be able to further convert the original analogy signal to digital code.

Adaptive systems have the property of automatically redistributing the bandwidth of the communication channel between individual sources, taking into account the current band of their spectrum. All primary devices are presented as a set of primary sensors connected via analogy-code converters (analogy frequency) and microcontrollers to the local network. The management of peripheral complexes and the implementation of general monitoring of working conditions is carried out by the data processing and analysis centre, is a communications server and database.

In order to increase the efficiency of communication channels, it is important to exclude the transmission of no interest messages. The bandwidth amount of the communication channel allocated to each message source is variable. The bandwidth redistribution principles of communication channels between message sources are implemented by adaptive systems of data collection and transfer [24].

<u>Steps 2-4 – Physical factors actual values assessment, comparison with maximum permissible concentration (MPC) or maximum permissible level (MPL) and the working conditions class establishment</u>

The working conditions class is established in accordance with hygienic classification of labour [18,19]. The hygienic classification of labour is based on the principle of differentiation of working conditions assessment, depending on actually identified levels of impact of the working environment and work process factors, with account of their possible harmful impact upon workers' health.

Table 3 presents the working conditions classes by some workplace environmental physical factors. The occupational risks assessment is carried out by applying one of the well-known methods [22], but regarding enterprises for glass products manufacture, it is recommended to use the occupational risks assessment index.

<u>Steps 5-8 – Physical factors actual values assessment, comparison with MPC (or MPL) and the working conditions class establishment</u>

Physical factors actual values assessment is carried out by comparing these values with the corresponding values of MPC (or MPL). If there is an excess of at least one physical factor over the MPC (or MPL), then there must be a transition to step 4. Otherwise, there should be a transition to step 8.

The technological processes analysis is necessary to identify the causes that led to the physical factors values excess and to develop protective measures. To evaluate protective measures in the process of their planning, expert methods can be applied. The planned protective measures implementation should reduce the values of physical factors to values that do not exceed the MPC (or MPL). However, in order to confirm of these measures effectiveness, it is necessary to conduct comprehensive monitoring. Thus, step 7 includes the implementation of the set of tasks (Fig. 3).

Table 3.
Working conditions classes by some environmental physical factors

No.	Workplace environmental physical factors names, (units)		Acceptable level of MPC	Working conditions class (work level with heavy and harmful working conditions)				
				3(1)	3(2)	3(3)	3(4)	4
1	Noise, dBA		< 80	The sound levels, up to (inclusive)				
				85	95	105	115	>115
2	Local vibration, dB		112	The exceeding the MPL, to the specified value (inclusive)				
				3/1.4	6/2	9/2.8	12/4	>12/4
3	Air dustiness, mg/m^3		MPC for each substance	The multiplicity of excess MPC, times				
				1.1-3.0	3.1-10.0	10.1-15.0	>15.0	–
4	Relative humidity, %			The exceeding the MPL, %				
		Warm season	65 at 26°C	less than 25	more than 25	–	–	–
		Cold season	75	less than 15	more than 25			

Note:
Permissible working conditions (Class 2) are characterized by such levels of environmental factors and the labour process that do not exceed the levels established by hygiene standards for workplaces. Possible changes in the functional state of the body are restored during regulated rest or at the beginning of the next shift and should not have an adverse effect in the near and remote period on the state of health of the worker and his offspring. The permissible class corresponds to safe working conditions.
Harmful working conditions (Class 3) are characterized by the presence of production factors that exceed hygienic standards and have an adverse effect on the body of the worker and (or) his offspring. Depending on the level of excess standards, the factors in this class are divided into four degrees of harm:
3(1) – cause reversible functional changes of the body;
3(2) – lead to persistent functional disorders and morbidity;
3(3) – lead to the development of occupational pathology in mild form and the growth of chronic diseases;
3(4) – lead to the emergence of pronounced forms of occupational diseases, a significant increase in chronic and high rates of morbidity with temporary disability.
Traumatic (extreme) working conditions (Class 4) at which levels of production factors are such that their exposure during work or part of it creates a threat to life and (or) a high risk of severe acute occupational diseases.

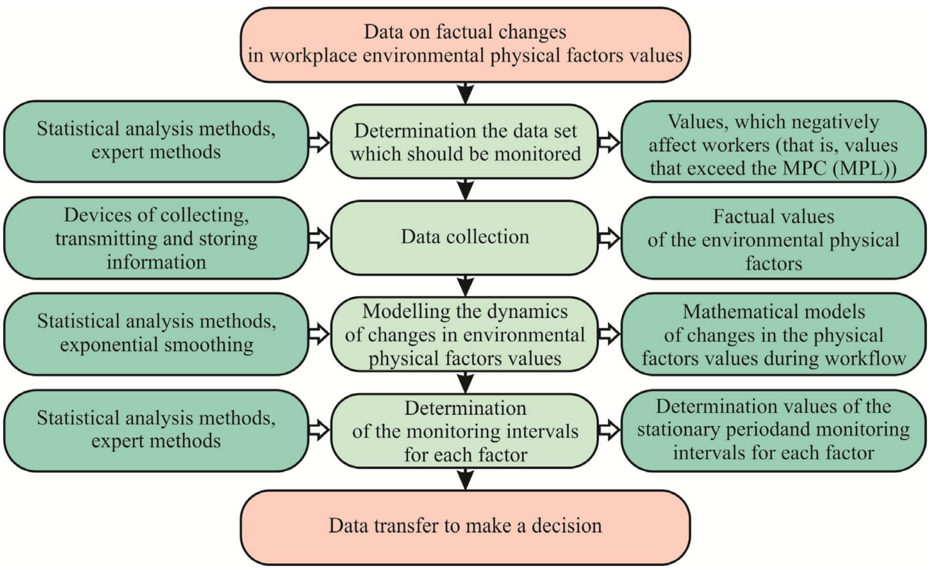

Fig. 3. The set of tasks to perform in step 7

Table 4.
The environmental analysis at workplace of the glass products manufacturing on the basis of physical factors experimental values [20]

No.	Name of environmental physical factors on the workplace	Number of measurements (n)	Period of stationarity (T), min	Interval of control ($\overline{\Delta}$), min
1	Noise	200	28	9
2	Vibration	200	20	7
3	Dust	200	9	3
4	Relative humidity	200	66	22

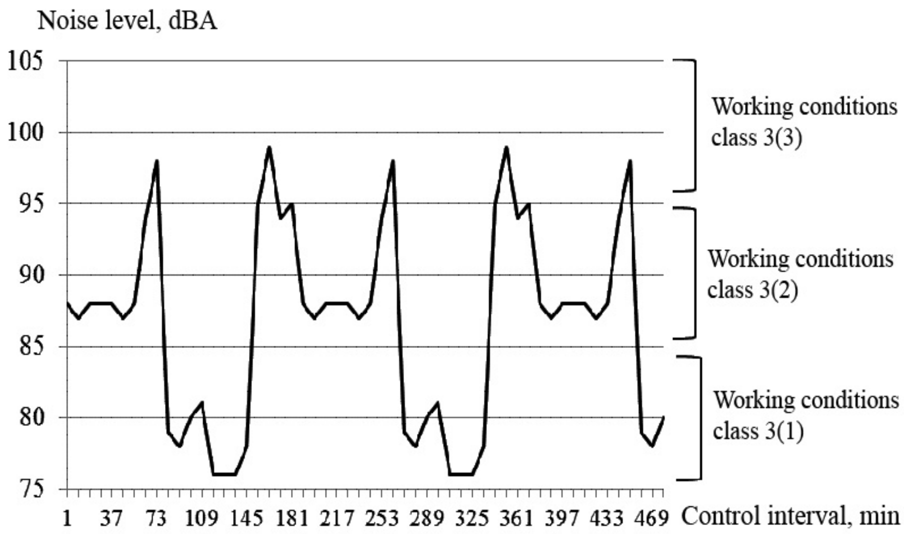

Fig. 4. Changes in noise values during the work shift

The expectation of the next session of the current control of the workplace environmental physical factors (step 8) determines the production situation when the values of all controlled factors are within acceptable limits, so there is no need for an additional protective measure.

3.2. Implementation of the proposed algorithm

The implementation of the proposed algorithm for substantiating managerial decisions to reduce the negative impact of workplace physical factors is shown by the example of four workplace environmental physical factors in the workshop for the transportation, preparation and mixing of materials in the glass products manufacture. It was previously determined that changes of the physical factors values (such as noise, vibration, dust and relative humidity) can be a stationary or non-stationary process. Therefore, the period of stationarity of the change in values and the necessary interval of control was determined (Tab. 4) [20].

Noise level assessment in the workplace

Data on factual changes in noise values during the work shift were used to assessment (Fig. 4). It was established that in accordance with [19], working conditions are assigned to the 3rd class (harmful working conditions).

Figure 4 shows that out of the total work shift time, 6 minutes workers work in conditions of class 3(3); 30 minutes – in conditions of class 3(2); 7 hours, 24 minutes – in conditions of class 3(1).

Vibration level assessment in the workplace

For the assessment, was used data on actual vibration values changes during the work shift (Fig. 5).

It was established that out of the total work shift time, 141 minutes vibration level exceeds the MPL (Tab. 3). At the same time, 7 minutes MPC values were exceeded up to 3 dBA (class 3(1)), 12 minutes – were exceeded up to 6...9 dBA (class 3(3)), 12 minutes – were exceeded up to 9...12 dBA (class 3(4)), 110 minutes – were exceeded up more than 12 dBA (class 4).

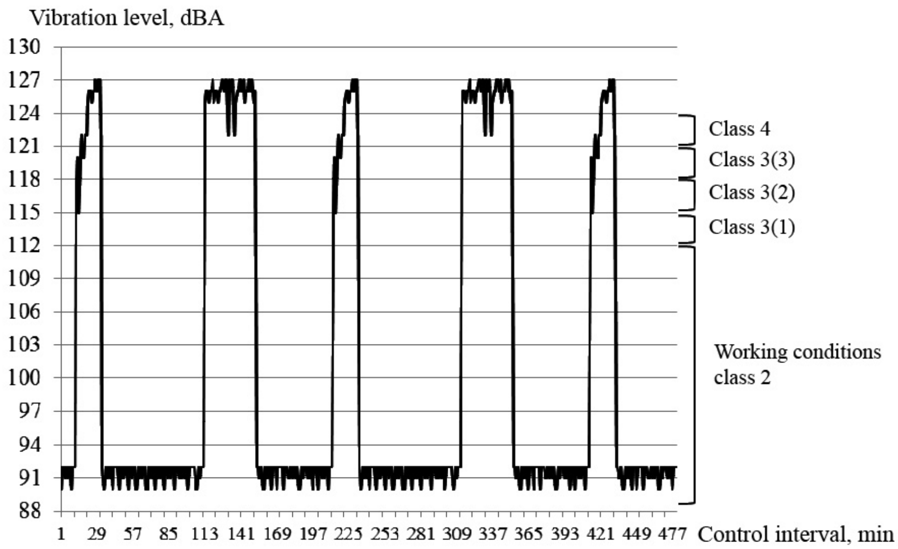

Fig. 5. Changes in vibration values during the work shift

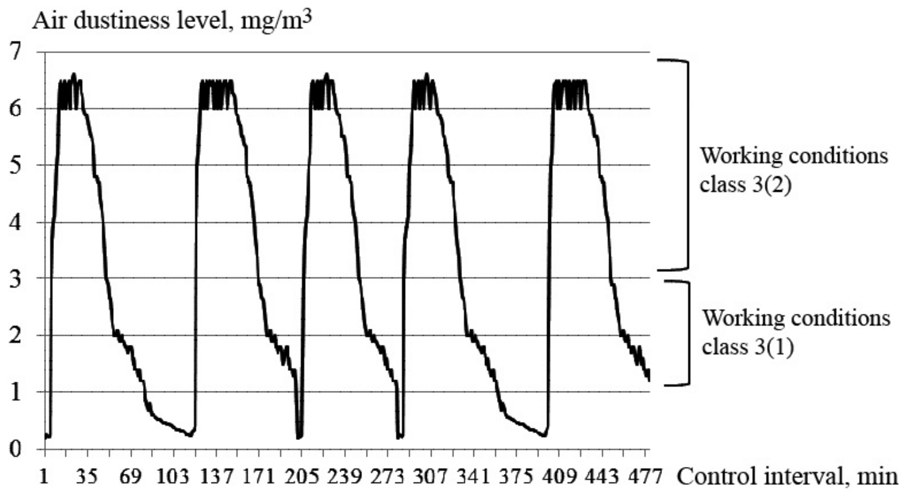

Fig. 6. Air dustiness changes during the work shift

From Figure 5 it is seen that during the work shift there are 5 vibrocycles. The duration of each cycle is more than 13 minutes, and for each cycle, an interval of working time is observed with an excess of the MPL by 12 dBA or more.

Air dustiness assessment in the workplace

For the assessment, was used data on actual air dustiness changes during the work shift (Fig. 6).

According to [18,19], for silicon dioxide (SiO_2) at a concentration of more than 60%, the MPC value is 1 mg/m^3 (silicon dioxide is the main material for the manufacture of glass, therefore, a large number of its particles are contained in air). Consequently, it was found that out of the total work shift time, 227 minutes workers are working in conditions corresponding to class 3(2) and 158 minutes – in the conditions of class 3(1).

Relative humidity assessment in the workplace

The relative humidity was estimated during the cold season and during the work shift. Production activity took place in various microclimatic conditions; therefore, a weighted average assessment of the class and harmfulness degree was calculated.

The overall assessment takes into account the degree of harmfulness and the exposure time at each level of the indicator and allows you to determine the time-weighted

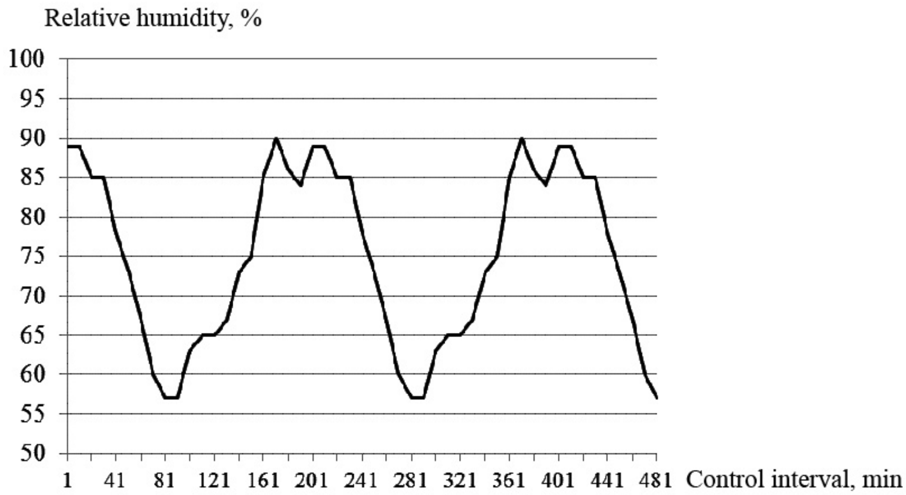

Fig. 7. Relative humidity changes during the work shift

variable assessment of the degree of harmfulness of the microclimate. Operating time in conditions of 1 or 2 classes of harmfulness [25] was not taken into account. The results are presented in Figure 7.

According to the measurement results (in the cold season), it was found that during a work shift, working conditions according to the indicator "relative humidity" for 165 minutes are defined as conditions corresponding to class 3(1). That is, the level of relative humidity exceeds 75%. In addition, in the conditions of a cooling microclimate, namely in unheated rooms (since the rooms are specially cooled to provide technological requirements for the glass products production) and in open space, working conditions must be assessed not lower than class 3(1).

Since the general assessment of the working conditions class is equal to the most dangerous class, the general class of working conditions is 4.

4. Discussion of monitoring results and possible protective measures

To identify the reasons of the physical factors values excess over the of MPC (or MPL) values, a technological processes analysis was carried out.

With a reduction in the time that environmental physical factors affect workers (that is, protection by time), as well as with the use of effective personal protective equipment, the risk level of health damage decreases. Consequently, working conditions can be assessed as less harmful.

The noise and vibration source at the studied workplaces are: mixer, vibrating screen, ventilation equipment and crushers. The sources of increasing dust concentration and relative humidity are the process of loading and unloading the mill, process of preparing the mixture. Appropriate measures to reduce the vibration level are the equipment design changes and the technological process correction. To reduce the level of vibration and noise, it is recommended to install special protective screens on mixers, vibrating screens and crusher, which will reduce the vibration level by 5 dB and the noise level by 10 dBA.

It was established by timing observations that the technological time of work with the machine is 141 minutes during work shift, and the work is organized in 5 technological cycles (the average cycle time is 28 minutes). According to [18,19], the total time should be no more than 65 minutes (i.e. 13 minutes per cycle) if the vibration level is 12 dBA above the MPL. However, the excess of this time is obvious. Therefore, a rational mode of operation is a mode based on 8 one-hour vibration cycles, subject to the organization of regular technological breaks of at least 10 minutes for each break.

If you install protective shields on the equipment, then the MPL values excess will be no more than 8 dBA. In this case, during each hour of work, the employee will work 19 minutes in conditions of increased vibration. Therefore, for an 8-hour shift, the total operating time in conditions of increased vibration will be 152 minutes. If the working mode will consist of 7 vibration cycles, then for each cycle the permissible operating time in conditions of increased vibration will be 20 minutes. The total operating time in conditions of increased vibration (class 3(1) per shift will

Table 5.
The working conditions class of the studied workplace before and after the measures implementation

Workplace environmental physical factors names	Working conditions class	
	before the measures implementation	after the measures implementation
Noise	3(2)	3(1)
Vibration	4	3(1)
Air dustiness	3(2)	3(1)
Relative humidity	3(1)	3(1)
Total working conditions class	4	3(1)

be 140 minutes. This mode of operation is possible provided that the crusher and the vibrating screen are technologically combined in operation time. Consequently, the implementation of the proposed measures contributes to the improvement of working conditions on the factor of “vibration” from class 4 to class 3(1) (Tab. 5).

To reduce the noise level, in addition to the proposed measures, it is advisable to provide acoustic treatment of the premises with materials that will reduce the noise level in the workshop by 10 dBA. In this case, working conditions will be improved and on the factor of “noise” will correspond to class 3(1) (Tab. 4).

The working conditions class on the factor of "air dustiness" is set as 3(2). Therefore, it is proposed to use bag filters with a cleaning efficiency in the range of 95-99% when loading and unloading the mill, preparing the charge and dosing and transporting the raw materials of the charge. This will reduce dust in the workshop by more than 20%. It is also advisable to seal the connecting elements of the equipment and apply local ventilation devices to prevent the dust spread. The implementation of these measures improves working conditions by the factor of "air dustiness" and ensures compliance with class 3(1) (Tab. 5).

Using the algorithm for making justified decisions to reduce the negative impact of the hazardous and harmful physical factors at the workplace makes it possible to adequately assess the working conditions state at the enterprise, identify deficiencies in the work organization, and develop an action plan to improve working conditions.

5. Conclusions

Based on the results of this study, the following conclusions can be formulated:

1) An algorithm has been developed that provides continual improvement of the OSH management system to improve overall labour productivity. The key positive features of the algorithm are the following:
   - Data collection: current monitoring of workplace environmental physical factors values is carried out in accordance with the justified monitoring intervals for each factor that provides the necessary and sufficient amount of data and eliminates the transfer of useless data;
   - Data transfer: prompt receipt of reliable information due to the exclusion from the production workshop of specialists who measure the physical factors values, and by improving the throughput of communication channels;
   - Operational determination of the working conditions class: with an accuracy of more than 90% mathematical modelling and forecasting of the physical factors values changes are provided. In the event of unforeseen changes in the factors values, this algorithm stage helps prevent negative effects on the employee health by introducing protective measures or removing the employee from the danger zone before the negative impact will begin.
2) As an example, the implementation of the algorithm for making justified decisions to reduce the negative impact of the hazardous and harmful physical factors at the workplace in the workshop for the transportation, preparation and mixing of materials in the manufacture of the glass products is shown. It has been established that, according to the factor of "noise", during the work shift, employees work in conditions corresponding to class 3(3); "vibration" – class 4 (the most dangerous class); "air dustiness" – class 3(2); "relative humidity" – class 3(1). Consequently, the general class of working conditions is 4.
3) Timely and informed (by mathematical modelling and forecasting) management decision-making on the implementation of proposed protective measures (according to the algorithm) made it possible to reduce the time of the dangerous effect of physical factors on the workers health, reduce the level of these factors and improve working conditions from class 4 to class 3(1).

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