Technosphere safety as a factor of product cost reduction

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Abstract. The article deals with the influence of The analysis of the relationship of a number of production factors, such as the level of illumination in the the most common harmful production factors in enterprises on employee fatigue and, as a result, on reducing labor productivity and increasing the cost of products and services due to low efficiency of working time and loss of working time due to injuries and diseases. workplace, the noise level in the workplace and the parameters of the microclimate on employee fatigue, labor productivity and the cost of products or services. The dependences of economic indicators on working conditions in the workplace are shown. Suggestions are given on the need for an economic assessment of the feasibility of investment in improving working conditions, taking into account the potential to reduce employee fatigue, increase their performance and, as a result, reduce the cost of products or services.

1. Introduction

In recent years, the problems of technosphere security have been in the focus of attention of all branches of government of the Russian Federation. Special attention is paid to minimizing professional risks. To this end, in 2017, a Memorandum was signed with the International social security Association on the entry of Rossi into the global campaign "Vision Zero", and a number of legislative acts were adopted. Since 2020, a system of mandatory assessment of occupational risks has been introduced, which becomes a natural step after the General assessment of jobs by working conditions. As of December 26, 2019, a special assessment of working conditions was conducted for 764.5 thousand employers for 32.5 million jobs. The number of employees employed in these jobs is 43 million. (with a total number of employees of about 74 million people).

As a result of a special assessment of workplaces, it was found that so far about 39% of workplaces do not meet sanitary and hygienic standards: the level of exposure to harmful industrial factors significantly exceeds the established standards. This means that more than 16 million people. (and taking into account not surveyed jobs and even more) are constantly under the influence of various harmful production factors of physical, chemical and biological nature. Moreover, these are factors whose normalization does not require significant investment and can be solved by organizational and managerial decisions. These include: noise level (in 2019, it did not meet sanitary and hygienic requirements in most sectors of the economy by 15.2 % of jobs during transportation and storage of products up to 32.6 % during mining; the state of the light environment did not meet from 1.3 % of jobs in construction to 3.5% in manufacturing; microclimate parameters from 1.1 % of jobs in construction and up to 5.4 - 5.5% of jobs in agriculture and manufacturing. However, non-compliance of sanitary and hygienic conditions in the workplace with regulatory requirements leads to increased fatigue and, as a result, reduced working capacity and, as a result, labor productivity [1-4].
To bring the working conditions at these workplaces to sanitary and hygienic standards, investments are needed in updating equipment and improving technologies, for which every employer needs serious justification for the expediency of such costs, understanding that not only social, but also quite a certain economic effect will be obtained.

It is not always obvious to employers that the cost of ensuring technosphere safety can affect the profitability of production, reducing the cost of products or services. Obvious factors that significantly affect the cost of production: material intensity, energy intensity, capital intensity of a unit of production, labor productivity. It is known that the reduction in the unit cost of the corresponding resources is limited by certain conditions. Thus, the reduction of the material is limited to the constructive characteristics and consumer properties of products, the possibility of reducing fondamenti – calculated value for the production capacity required to manufacture the specified product quantity. Only an increase in labor productivity is a real and sufficiently manageable reserve for reducing the cost of production.

The high cost of production is one of the leading reasons for the low efficiency and competitiveness of business and the entire Russian economy. Therefore, it is important to find and use all the reserves to reduce costs and improve the efficiency of the economy. According to experts, up to 60% of the cost depends on the level of labor productivity. This is a share in the cost of direct costs – wages, unified social tax, and depreciation. In addition, it is necessary to take into account indirect costs: due to the increase in labor productivity, the duration of the production cycle is reduced.

According to various studies, Russian enterprises are catastrophically behind European, Japanese and American companies in this indicator. The main reason for low labor productivity is not only outdated production assets, which enterprises quite objectively attribute to all production problems, but, above all, a low level of labor organization, production management, and creating conditions in the workplace that allow each employee to fully realize their potential.

The Concept of the country’s development until 2020 indicates the need for a four-fold increase in labor productivity, which is a key condition for Russia to reach the fifth place in the world in terms of gross domestic product and significantly increase the competitiveness of its products. To achieve this growth in labor productivity, it is necessary to increase it annually by an average of 13%. Therefore, increasing labor productivity is one of the most pressing problems in business today.

In our opinion, a significant number of enterprises (as shown above, at least 39% of jobs) have large reserves for increasing productivity, which do not require significant investment in their implementation (reducing the loss of working time, improving the organization of production and labor, rationalizing the structure of personnel, etc.). These are primarily factors of technosphere safety, and mainly harmful and dangerous factors in the workplace.

Therefore, the purpose of the work is to analyze the possible impact of harmful production factors on fatigue, performance, labor productivity and, ultimately, on the cost of products and services, and to develop proposals for reducing them.

### 2. Relation of labor productivity to the cost of products and services

The increase in labor productivity affects not only the growth of business efficiency, but also the reduction in the number of employees, which means the number of jobs that need to ensure the safety and security of their work, the cost of social protection measures for employees, etc., which will give an additional economic effect by reducing the cost of products and services[5-7].

The first direction-reducing the number of employees, is associated with the release of a certain number of employees, due to increased productivity, which is a consequence of reducing the labor intensity of products and reducing the loss of working time. In this case, the reduction in the cost of production can be determined by the formula:

$$E_t = S_{nw} \times S_{nw} \times k_s$$  \hspace{1cm} (1)

where $E_t$ – save the current production costs for salaries and social insurance, RUB.;
Snw – saving number of employees (number of redundant) as a result of the implementation of measures to improve productivity, people;
Snw – average annual wages of redundant workers, RUB.;
ks – coefficient taking into account contributions to the unified social Fund, shares of the units (XI = 1.26).

The second direction of cost reduction is associated with an increase in the productivity of the main workers and a corresponding increase in production, which leads to a relative decrease in conditional fixed costs in the cost of production:

\[ E_2 = \text{Feb} \times (1 + \text{Vp} \times 10^{-2}) - \text{Vp} \]

where \( E_2 \) is the reduction of production costs due to the relative saving of fixed costs, RUB.;
Feb - a base amount of fixed costs, RUB.;
Vp – increase production by increasing productivity of main workers, % (provided that the number of core workers remains unchanged, the increase of production volume in percentage numerically equal to the productivity growth of the major job);
Vp – value of conditionally fixed expenses in the planned (reporting) period, RUB.

The third direction of cost reduction is determined by the ratio of the growth rate of labor productivity and the average salary of employees:

\[ E_3 = Wf \times ks \times kr \]

where \( E_3 \) is the reduction of production costs due to the excess growth of labor productivity in comparison with the growth rate of the average wage, RUB.;
Wf – payroll in production costs, RUB.;
ks – coefficient taking into account contributions to the Unified social Fund;
kr – coefficient of excess of labor productivity growth in relation to wage growth.

The latter component allows you to get an additional effect in reducing the cost of production by reducing deductions to the social insurance Fund due not only to a relative decrease in deductions when labor productivity growth exceeds wage growth, but also by reducing deductions due to a decrease in the class of occupational risks.

3. Direct impact of harmful working conditions on cost
The presence of harmful and dangerous working conditions at the enterprise leads to additional costs, which can significantly increase the cost of production [1,8]:

\[ C_a = S + C + \text{Pv} + \text{Pf} + \text{Pm} + \text{Pp} \]

where S - surcharges for such work in comparison with regular rates;
C-compensation related to the calculation of working hours;
RV - cost of providing additional paid vacations;
Pf-cost of providing special meals;
Pm-cost of organizing primary and periodic medical examinations;
Pp - the cost of issuing protective equipment against harmful industrial factors.

The amount of increase in remuneration for employees engaged in work with harmful and (or) dangerous working conditions should not be less than 4 % of the tariff rate (salary) established for various types of work with normal working conditions). If the industry has a sectoral agreement, e.g., "Industry agreement on coal industry of the Russian Federation," the employees engaged in work with heavy, dangerous and especially harmful working conditions, according to special lists, tariff rates increased by 10% and 20 %.

In addition, reduced working hours (no more than 36 hours per week) reduce the employee's annual productivity by another 10%. In addition, it is necessary to provide additional annual paid leave to employees whose working conditions are classified as harmful or dangerous working conditions in the
amount of at least 7 calendar days, which reduces the productive time of employee participation in the production process by more than 3 percent and affects the cost of products and services.

4. **Indirect influence of harmful production factors on the cost price. Influence of the state of the light environment on fatigue and labor productivity**

Lighting is one of the most important conditions for productive and safe work. In various types of industrial activities, the number of accidents related to lighting in one way or another is on average 30-50% of the total number. In rough work, about 1.5% of serious fatal injuries occur due to low light conditions. Eye injuries in these jobs account for 7.8 to 31.1% of the total number of accidents, with 18 to 25% of eye injuries associated with poor lighting in the workplace. And injuries are the loss of working time to restore the health of affected employees (in 2019, such losses amounted to an average of 50 working days), the need to replace the injured employee with a temporary one, which again affects labor productivity and, as a result, the cost of production.

Through the visual apparatus, a person receives about 90% of information. Sufficient lighting has a tonic effect, improves the flow of the main processes of nervous activity, stimulates metabolic and immunobiological processes, and affects the daily rhythm of physiological functions of the human body. Generalized patterns of the influence of workplace illumination on some important production parameters are shown in Fig. 1 [9,10]. Practice shows that only by improving lighting in the workplace, an increase in labor productivity from 1.5 to 15% was achieved.

![Figure 1. Generalized dependence of some production parameters on workplace illumination.](image)

Labor productivity is affected not only by the level of illumination, but also by the spectral composition of light. Research shows that if the output of people, in natural light, if you take it as 100%, then in red and orange lighting it is only 76%.

The unfavorable light environment of industrial premises combined with high visual load (viewing small objects at close range) is the cause of fatigue of the visual analyzer, leading to a decrease in performance, labor productivity, and even to the development of certain visual defects. For example, long-term performance of accurate visual work at close range with insufficient levels of visible radiation, when the lens muscles are constantly straining, can lead workers in some professions (watchmakers, electronic equipment assemblers, etc.) to the development of so-called false myopia. If the work continues under the same conditions, then false myopia can turn into true myopia, in which there is already an increase in the anterior-posterior size of the eyeball.

Unfavorable conditions of visual work can also lead to early (up to 40 years of age) development of senile farsightedness, when the lens loses its elasticity.
However, too bright light blinds, reduces visual functions, leads to overexcitation of the nervous system, reduces performance, and disrupts the mechanism of twilight vision. Exposure to excessive brightness can cause eye burns, keratitis, cataracts, and other tissue disorders.

In the course of many scientific experiments, scientists have come to the conclusion that the excess volume of blue color in the spectrum of most LEDs created on the basis of a blue crystal directly and negatively affects the physiological processes in the human body, in particular, the production of the hormone melatonin. (Melatonin regulates our daily rhythms and is responsible for the frequency of sleep and wakefulness. It is this hormone that sets up the human body to rest and sleep at the end of the day).

An excessive dose of blue light, which is present in the spectrum of conventional LED light sources based on blue crystals, slows down the secretion of melatonin, which leads to a disorder of circadian rhythms, deterioration of health, causes insomnia and discomfort, and, as a result, can provoke: a decrease in immunity and the development of cancer; diseases of the cardiovascular system; hypertension, coronary heart disease; violation of reproductive function; diabetes, etc. [11-13]. Blue light through the ganglion cells and centers of the hypothalamus affects the epiphysis, which synthesizes melatonin, then the pituitary and adrenal glands, which produce cortisol and more than 50 different steroid hormones.

The solution to the problem can be a combination of purple crystals and phosphors (red-green-blue), which, for example, using TRI-R technology allows you to synthesize LEDs with spectra close to the spectrum of sunlight (color rendition of at least 95 Ra), with different color temperature, and eliminate the shortcomings in the spectrum of the traditional led (blue crystal covered with yellow-red phosphor).

TV the last years there was also the ideology of "circadian-friendly led light." Unlike conventional LED light sources based on blue crystals, innovative light sources based on a purple led produced using TRI-R technology do not carry an excessive amount of blue in their spectrum and are completely safe for the eyes: they do not lead to photochemical burns of the retina and its degradation over time. TRI-R light sources do not negatively affect human physiology, i.e. they do not lead to disorders of circadian rhythms that lead to serious diseases.

The fourth lighting option is on the way, and the technology called FIPEL (FIPEL from Field-induced polymer electroluminescent-field-induced polymer electroluminescence) is already considered to be the first in the last 30 years to claim the title of a new energy-saving lighting technology. A special type of plastic is used here, which, when interacting with an electric current, induces a bias current and emits light.

The new light source is made of several layers of ultra-thin plastic, each layer being 100,000 times thinner than a human hair. The plastic is placed between two electrodes, one of which is aluminum, and the other is transparent and also conductive. When the current passes through the device, the plastic is stimulated and glows. The technology is based on polyvinylcarbazole polymer doped with monostructured nanotubes and iridium compounds. The researchers achieved exceeds the brightness of 18,000 CD/sq m, which already allows to cover a large area.

Thus, new technologies can solve the problem of ensuring normal sanitary and hygienic conditions for the visual organs of employees and, by reducing fatigue, increase labor productivity and affect the reduction of the cost of products or services.

5. Impact of noise on fatigue and productivity
Virtually no production process is complete without generating various sounds that a person perceives as noise. For a person, noise with a sound pressure level of 30..45 dB is familiar and does not bother him, up to 40..70 dB – creates an additional load on the nervous system, with prolonged exposure to a person can cause neurosis, over 80 dB – leads to professional hearing loss, over 130 dB – rupture of the eardrum, over 160 dB – a likely fatal outcome [14]. Noise at work weakens the attention of the worker, increases energy consumption with the same physical activity, slows down the speed of
mental reactions. Under the influence of systematic noise, labor productivity in some cases decreases by 30% or more (Fig. 2), and the number of errors in calculation work increases by more than 50%.

Noise is also a cause of impaired memory, attention, visual acuity, and sensitivity to warning signals given by personnel serving in-plant transport (forklifts, electric cars, overhead cranes, etc.), which can cause an accident [12]. The effect on the hearing organs is manifested in the form of hearing loss (neuritis of the auditory nerve) or complete hearing loss. The probability of hearing loss is determined by the value of the equivalent sound level, the duration of its action, and the individual sensitivity of the person. Under the influence of intense noise (85-90 dB), first of all, the auditory sensitivity to high tones decreases. If the noise level exceeds 145 dB, the eardrum may rupture. Therefore, it is forbidden to work in conditions of a noise level higher than 135 dB.

![Figure 2. Approximate regularities of the influence of noise level (dB) in the workplace on labor productivity.](image)

The adverse effects of acoustic vibrations do not only lead to hearing loss. Pathological changes under the influence of noise are considered as a noise disease that has the following symptoms: decreased auditory sensitivity, changes in digestive function (decreased acidity), cardiovascular insufficiency, neuroendocrine disorders, irritability, headaches, dizziness, memory loss, fatigue, decreased appetite, ear pain, etc.

Even a small noise (50-60 dB) creates a significant psychological burden on the nervous system, especially in people with intellectual work. This load varies depending on age, health status, type of work, state of mind, etc. The impact of noise also depends on the person's attitude to it: the noise created by the person himself has almost no effect on it, and extraneous noise can be very annoying.

Excessive noise in the body reduces the immune barrier and increases the frequency of diseases, and the most diverse-from colds to gynecological. Studies show that in noisy enterprises, the incidence rate is 20% higher than the average. Older people are most sensitive to noise. For example, 46% of people under the age of 27 respond to noise, 57% of people aged 28-37, 62% of people aged 38-57, and 72% of people aged 58 and older. A large number of complaints about noise in the elderly are obviously related to the age characteristics and the state of the Central nervous system of this population group. This should be taken into account by employers when the relative number of age-related employees increases due to an increase in the retirement age.

The economic aspect is due to the fact that noise affects labor productivity, and the elimination of the consequences of diseases from noise - significant social benefits. Increasing the noise level by 1-2 dB leads to a 1% reduction in labor productivity. If the noise level increases by only 3 dB per working day, the employee receives twice the amount of noise, and therefore the effective work time is
reduced. Studies of domestic and foreign scientists have shown that under the influence of noise, labor productivity generally decreases by 10%. Professor G. Legman proved that you can expect to increase productivity by 9%, reduce the number of errors in written work by 29%, reduce the incidence of diseases by 37% while providing noise control measures.

6. The influence of microclimate parameters on the performance

Microclimate parameters have a significant impact on a person's well-being, fatigue, and performance. It is established that at an air temperature of more than 24 deg. and less than 21 degrees, human performance begins to fall (Fig. 3). Prolonged exposure to high temperatures, especially in combination with high humidity, can lead to a significant accumulation of heat in the body and the development of overheating of the body above the permissible level – hyperthermia – a condition in which the body temperature rises to 38-40 degrees. There is a headache, weakness, nausea, vomiting. The pulse and respiratory rate are accelerated, and the content of residual nitrogen and lactic acid in the blood increases. There is pallor, blue skin, dilated pupils, sometimes there are convulsions, loss of consciousness.

Maximum temperatures are determined for a person depending on the duration of their exposure and the protective equipment used. The maximum temperature at which a person can breathe for several minutes without protective equipment is about 116 deg.

When the temperature decreases relative to the standard, the carbohydrate metabolism changes. The increase in metabolic processes with a decrease in temperature by 1 oC is 10%, and with intensive cooling, it can increase by 3 times compared to the level of the main exchange.

Figure 3. General regularity of the influence of temperature in the workplace on labor productivity.

Further exposure to cold affects breathing: it becomes non-rhythmic, the frequency and volume of inspiration increase, and carbohydrate metabolism changes. There is a muscle contraction (tremor), in which external work is not performed and all the energy of muscle contraction is converted into heat. This allows you to delay the decrease in the temperature of internal organs for some time. Cold injuries may occur due to exposure to low temperatures.

Human tolerance of temperature, as well as its heat perception, largely depends on humidity and air velocity. The higher the relative humidity, the less sweat evaporates per unit of time and the faster the body overheats. So, at $t=18$oC, $v_0=0$, $v_60%$ - the amount of heat given by a person to the environment during evaporation of moisture is about 18% of the total heat transfer. When the temperature increases to 27 degrees, the proportion of $Q_{isp}$ increases to 30% and at 37 degrees. reaches 100%.
High humidity at a temperature of more than 30 degrees has a particularly adverse effect on a person's thermal well-being, since almost all the heat released is released into the environment when sweat evaporates. When humidity increases (more than 80%), sweat does not evaporate, but drips from the surface of the skin. There is a so-called torrential flow of sweat that exhausts the body and does not provide the necessary heat transfer.

Insufficient air humidity (less than 20%) can also be unfavorable for humans due to intensive evaporation of moisture from the mucous membranes, their drying out and cracking, and then contamination by pathogens.

Dehydration of the body by 6% causes a violation of mental activity, reduced visual acuity. 15-20% dehydration leads to death. Therefore, when a person stays indoors for a long time, the permissible humidity is 30-70%, and the optimal values are 40-60%. Contrary to popular belief, the amount of perspiration does not depend much on the amount of liquid consumed. A person who works without drinking for 3 hours produces only 8% less sweat than when the lost moisture is fully recovered.

For a person, it is considered acceptable to reduce his weight by 2-3% by evaporation of moisture – dehydration of the body. Dehydration by 6% leads to a violation of mental activity, reduced visual acuity, evaporation of moisture by 15-20% leads to death.

Together with sweat, the body loses a significant amount of mineral salts (up to 1%, including 0.4-0.6 NaCl). Under adverse conditions, the loss of fluid can be 8-10l per shift and up to 60 g of table salt (140 g of NaCl in the body). Loss of salt deprives the blood of the ability to retain water and leads to disruption of the cardiovascular system.

It has been experimentally established that optimal metabolism and, consequently, maximum labor productivity occur if the components of the heat transfer process are within the following limits: Qk + Qt = 30%, Qt = 45%, QIS = 20%, QB = 5%. This balance is characterized by the absence of tension in the thermoregulation system. It is to this state that it is necessary to strive to improve performance and achieve the goal of reducing the cost of production.

7. Conclusion

The main sources of economic efficiency from measures to improve technosphere safety by improving sanitary and hygienic conditions at the workplace of employees of enterprises is to reduce the cost of products and services with an increase in labor productivity due to:

- improving human performance as a result of reducing fatigue caused by adverse working conditions, reducing or completely eliminating in-shift downtime, etc.
- reducing the labor intensity of products due to the reduction of unproductive labor costs caused by adverse conditions;
- increase the effective working time Fund as a result of reducing the loss of working time due to temporary disability due to injuries and diseases associated with unfavorable working conditions;
- improving the efficiency of the use of machinery and equipment.

These factors will affect the cost of production as follows:

\[ S = \frac{\sum Cd + \sum Ck}{Va} \]  

Where Cd - is the direct cost,  
Ck - is the cost of compensating conditions. labour's;  
Va - annual volume of products (services) produced.

The lower the productivity, the fewer products or services, and the higher the cost. Or the company must compensate for low productivity by increasing the number of employees, and this, if there are jobs with harmful and dangerous working conditions, will not only increase the cost of labor remuneration and deductions, but also, as noted above, increase the cost of mandatory compensation.

Thus, the employer needs to economically assess the feasibility of bringing the company's workplaces to sanitary and hygienic standards and the real impact of changes on the cost of products and services.
The analysis shows that by reducing the level of the light environment, noise, microclimate parameters, etc. to sanitary and hygienic standards on 39% of workplaces of the enterprises of the Russian Federation (and this is, as shown above - at least 16 million employees), it is possible to increase labor productivity by at least 10%, which on average in the country will give an increase in labor productivity by almost 7%.

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