EXPERIMENTAL EVALUATION OF COMBINED EFFECTS OF RISK FACTORS IN WORK ENVIRONMENT

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Abstract. In mechanical engineering plants there are many negative factors which affect the workers and present strain on the organism of the workers during their active jobs. Because of this, it is important to find out the extent of the work load, which is connected with the comfort of the worker. When evaluating the work load effects, it is necessary to take the synergism of all risk factors in effect into consideration as opposed to individual risk factor evaluation. The aim of this paper is to lay out the possibilities of complex work environment evaluation. The basis for this is the basic presumption, that there are several risk factors affecting the human body during the work process.

Key words: complex assessment, work environment, risk, experiment.

Introduction

Risk is generally described as the rate of hazard. If this phenomenon is looked at in the context of concrete industrial activities, then risk represents identifiable and quantifiable rate of hazard to life, health, material or the environment [1].

Complying with principles of safe work and feeling of overall operational safety at work without feeling of the possibility to come by a work related disorders and injuries create good work environment and stimulate the workers [2].

Currently risk evaluation is understood as a process of evaluating of the probability and severity of the work environment factor harmful effects on the human body which has defined conditions, from defined sources. It consists of the determination of the hazard, evaluation of the exposure, defining the relation of dose and effect and characterization of the risk and determination of the evaluation uncertainty.

According to [3] these parts the evaluation process can be defined:

- evaluation of typical factors of the work environment;
- evaluation of requisite factors of the work environment;
- evaluation of chosen factors of the work environment;
- evaluation of classes of factors of the work environment;
- evaluation of the complex work environment quality.

In practice, the prevailing part is the evaluation of the requested factors of the work environment. It is a partial evaluation of the effects of each requested factor affecting the human body. It is necessary to understand that this method does not provide for interactions of all existing factors of the work environment, which is why it is necessary to aim on evaluating complex quality of the work environment to incorporate the synergism of all negative factors of the work environment in effect and not just their individual effects. This area of the problem has been the object of multiple papers [4-9].

Materials and methods

In this paper the possibility of complex work environment evaluation by means of mathematical modeling is described through an experiment. The basic principle employed is that many risk factors affect the human body in the work process.

First of all, it is necessary to determine the intensity and duration of the evaluated risk factor effect on the worker's body. Quantification of the effect of individual parameters of the work environment on the human body is very difficult. Finding the mathematical dependency between the complex state of the work environment and its effects on the human body is even more difficult (although the dependency between improving the work environment and increase in work performance is proven).

Results and discussion

The basic presumption in the experiment was that multiple risk factors affect the worker's body. In complex work environment evaluation the interaction of all risk factors is observed. This particular experiment was focused on four chosen factors affecting the worker's health and comfort – noise, lighting, temperature and energy expenditure.

The input values of noise, lighting and temperature were set in the first step. These were combined at three different levels (Table 1). Particular input values in Table 1 were monitored by the measuring equipment Brüel & Kjær 2239 (noise), Voltcraft MS 4 IN 1 # DT-8820 (lighting) and QUESTemp36 (temperature). The factor of energy expenditure was measured through a pulse measurement device Polar S610i.

Table 1

Values of set risk factors

Risk factor	Level		
	1	**2**	**3**
Noise, dB	70	80	90
Lighting, lx	50	250	500
Temperature, ºC	17.5	24.5	28.5

A multivariate analysis (Saaty method) was employed for complex work environment evaluation, through which the significance of individual chosen risk factors was evaluated.

The results of the measured and set values of the risk factors are shown in Table 2. Since individual measurements lasted for 30 minutes, it was necessary to convert the measured data to an 8 hour shift exposure.

Table 2

Set and measured values of selected risk factors with resulting complex load

Measure-ment	Noise $L_{AEX,8h}$, db	Lighting E_m, lx	Operational temperature t_o, ºC	Shift energy expenditure, MJ	Complex load, q_c
1	79.7	250	17.5	9.74	**1.20**
2	89.7	250	17.5	14.78	**1.52**
3	69.7	50	17.5	15.46	**2.45**
4	89.7	50	17.5	8.74	**2.11**
5	79.7	50	17.5	9.48	**2.13**
6	69.7	500	17.5	8.06	**0.94**
7	79.7	500	17.5	5.32	**0.78**
8	89.7	250	24.5	12.77	**1.38**
9	69.7	250	24.5	10.75	**1.18**
10	79.7	250	24.5	9.41	**1.19**
11	79.7	50	24.5	12.77	**2.29**
12	89.7	50	24.5	7.39	**2.03**
13	69.7	50	24.5	10.75	**2.13**
14	69.7	500	24.5	9.41	**1.04**
15	89.7	500	24.5	8.74	**1.06**
16	79.7	500	24.5	9.41	**1.07**
17	79.7	50	28.5	8.74	**2.10**
18	69.7	50	28.5	8.06	**2.02**
19	79.7	500	28.5	7.39	**0.95**
20	69.7	500	28.5	8.74	**1.01**

For noise it was necessary to convert the set value to equalized level of sound with A weighting (L_{Aeq}) and then into $L_{AEX,8h}$ – normalized level of noise exposure. Providing that the air flow velocity was $v_a < 0.2$ m.s^{-1} it was possible to convert the temperature of the globe thermometer t_g into operational temperature t_o. For correct determination of the energy expenditure it was necessary to convert kcal into MJ, because in the Regulation of the Ministry of Health of the Slovak Republic no. 542/2007 Coll. energy expenditure is presented in MJ.

The results of complex evaluation are shown in Table 2 and Fig. 1. The reference value of q_c is 1.

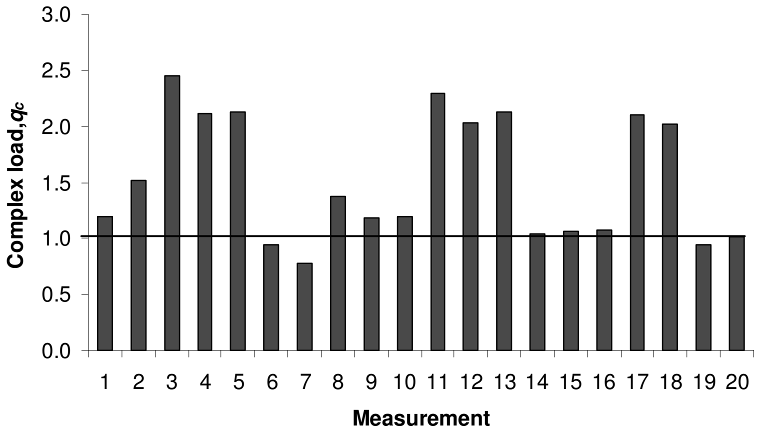

Fig. 1. **Depiction of the complex load q_c**

From Figure 1 it is obvious, that if the measured $q_c < 1$, the state of the work environment was deemed satisfactory. In cases, where at least one of the risk factors overstepped the limit value $q_c > 1$, the work environment was deemed highly harmful. If the values of the q_c are close to 1, the work environment state can be deemed moderately harmful or conditionally satisfactory.

Next in the experiment it was needed to focus on those measurements, where the q_c was close to 1.

Experiment 1

In this case the process went as follows: noise levels were manipulated, various durations were set for noise levels of 80/75 dB, 85/80 dB, 80/75 dB a 85/80 dB (Table 3 and Fig. 2).

Table 3

Results of q_c with manipulation of noise levels

Measurement		**6**	**19**	**20**
Complex load q_c		0.94	0.95	1.01
duration	$L_{AEX.8h}$, dB	-		
80 dB – 4 h; 70 dB – 3.5 h	78.1	0.96	0.94	1.03
80 dB – 6 h; 70 dB – 1.5 h	79.1	0.97	0.94	1.04
80 dB – 7 h; 70 dB – 0.5 h	79.5	0.97	0.94	1.04
85 dB – 4 h; 80 dB – 3.5 h	83.1	0.98	0.96	1.05
85 dB – 6 h; 80 dB – 1.5 h	84.1	0.98	0.96	1.05
85 dB – 7 h; 80 dB – 0.5 h	84.5	0.98	0.96	1.05
80 dB – 6 h; 75 dB – 5 h	79.8	0.97	0.95	1.04
80 dB – 8 h; 75 dB – 3 h	80.5	0.97	0.95	1.04
80 dB – 10 h; 75 dB – 1 h	81.1	0.97	0.95	1.04
85 dB – 6 h; 80 dB– 5 h	84.8	0.98	0.96	1.05
85 dB – 8 h; 80 dB – 3 h	85.5	0.99	0.96	1.05
85 dB – 10 h; 80 dB – 1 h	86.1	0.99	0.96	1.06

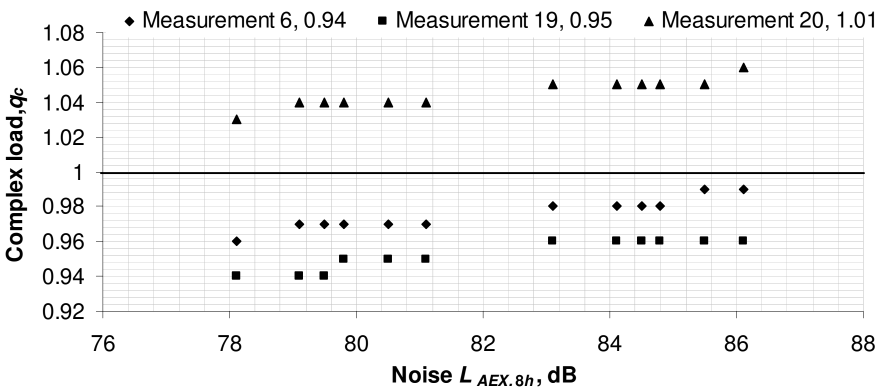

Fig. 2. **Depiction of q_c with manipulated noise level**

Experiment 2

This experiment was carried out with manipulates in the work shift energy expenditure. Two alternatives – with energy expenditure of 7,5 MJ and 8,5 MJ were carried out; other factors unmanipulated (Table 4 and Fig. 3).

Table 4

Results of q_c with manipulation of energy expenditure

Measurement	6	19	20
Complex load q_c	0.94	0.95	1.01
Shift energy expenditure, MJ	-		
8.5	1.04	1.02	0.99
7.5	0.90	0.95	0.92

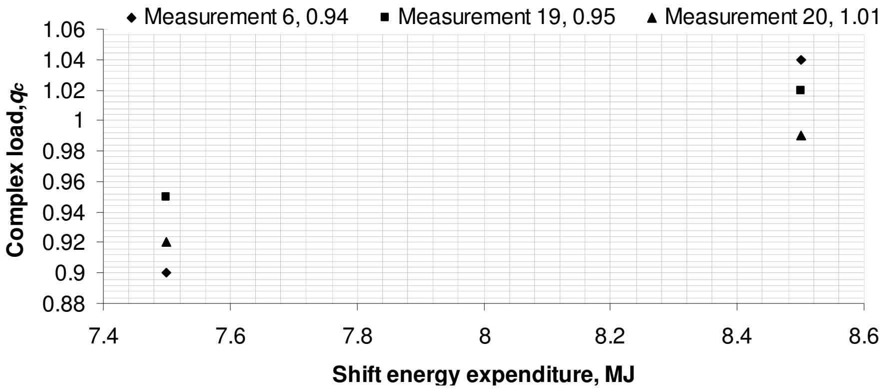

Fig. 3. **Depiction of q_c with manipulated energy expenditure**

Experiment 3

In this experiment the manipulations were made for noise levels and energy expenditure simultaneously. $L_{AEX,8h}$ was manipulated to 74,7 dB and 79,7 dB, along with the manipulations of energy expenditure to 8 and 8.5 MJ (Table 5, Fig. 4 and 5). Fig. 4 depicts the development of q_c with energy expenditure 8 MJ at different levels of $L_{AEX,8h}$ and Fig. 5 depicts the development of q_c with energy expenditure of 8.5 MJ at different levels of $L_{AEX,8h}$.

Table 5

Development of q_c with noise level and energy expenditure manipulations

Measurement		6	19	20
Complex load q_c		0.94	0.95	1.01
Shift energy expenditure, MJ	$L_{AEX,8h}$, dB	-		
8.0	74.7	0.95	0.97	0.97
8.5	74.7	0.98	1.01	1.01
8.0	79.7	0.96	0.99	0.99
8.5	79.7	1.00	1.02	1.02

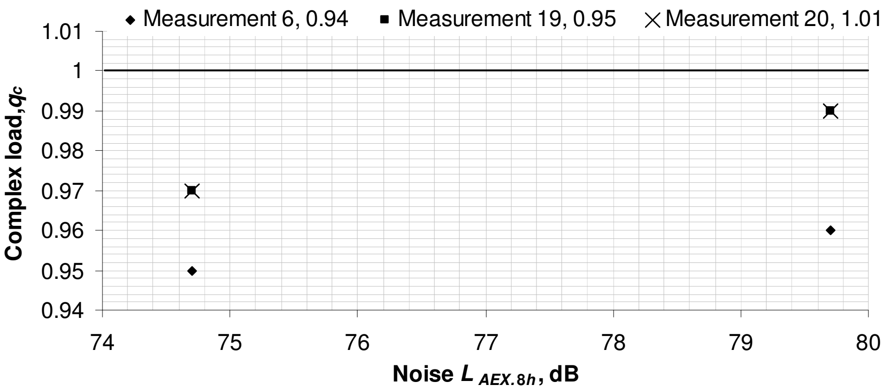

Fig. 4. **Depiction of q_c with noise and energy expenditure manipulations development with 8 MJ at various $L_{AEX,8h}$**

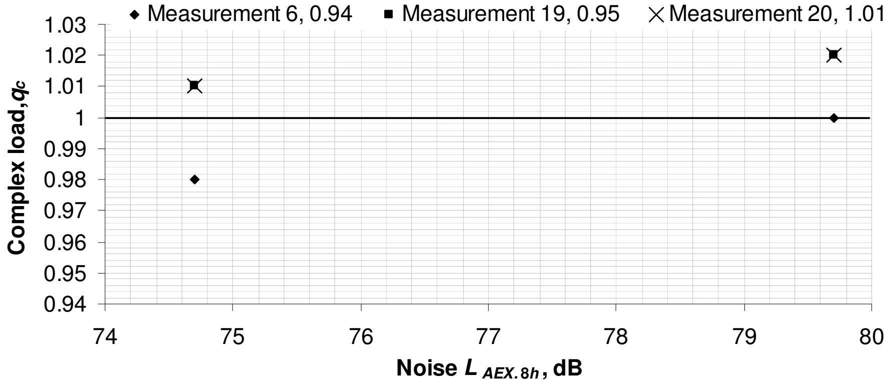

Fig. 5. **Depiction of q_c with noise and energy expenditure manipulations development with 8.5 MJ at various $L_{AEX,8h}$**

Experiment 4

In the preceding experiments the input parameters were gradually manipulated. The only risk factor with unaltered values was lighting. The last experiment was therefore aimed on lighting parameter manipulation to 450 lx and 250 lx (Table 6 and Fig. 6).

Table 6

Results of q_c in lighting parameter manipulation

Measurement	6	19	20
Complex load, q_c	0.94	0.95	1.01
Lighting, E_m, lx	-		
450	0.95	0.96	1.02
250	1.05	1.06	1.12

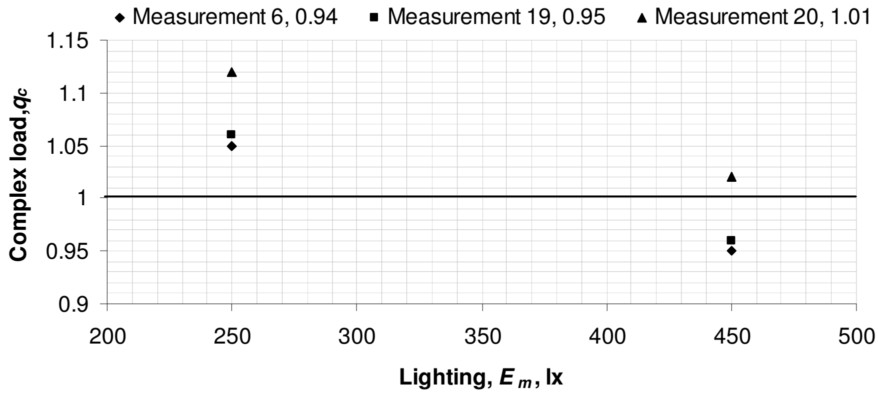

Fig. 6. **Depiction of q_c in lighting parameter manipulation**

According to the results of the experiments the following can be stated: for all experiments the value of the complex load parameter q_c increases with work environment degradation (risk factor increase). As can be seen from the noise level manipulations, if the change was small, the response of the complex load parameter was small or none at all.

With manipulations of the energy expenditure to 7.5 MJ the complex load parameter changed from the area of unsatisfactory work environment to satisfactory, manipulating the energy expenditure to 8.5 MJ resulted into changing the state to unsatisfactory in measurements No. 6 and 19. On the other hand, in measurement 20 the complex load parameter changed to satisfactory (0.99), which is not practically possible, because the energy expenditure of 8.5 MJ is not permissible according to the legislation.

The experiment with simultaneous manipulation of noise levels and energy expenditure showed that with $L_{AEX,8h}$ = 74.7 dB and shift energy expenditure of 8 MJ the state of measurement No. 20 changed to satisfactory, which is correct, the state of measurement No. 19 changed to unsatisfactory with shift energy expenditure of 8.5 MJ. The same experiment was carried out with $L_{AEX,8h}$ = 79.7 dB and shift energy expenditure of 8 MJ and 8.5 MJ. In measurements No. 19 and 20 with shift energy expenditure of 8 MJ the value of q_c was 0,99, so the work environment can be deemed conditionally satisfactory. For the shift energy expenditure of 8.5 MJ the state of the work environment was on the borderline in measurement No. 6, the $q_c = 1$.

The last experiment consisted of manipulations of the lighting parameter. The state of the complex load parameter did not change when the lighting was set to 450 lx, due to low weight of the lighting factor in the Saaty matrix. When the lighting was lowered to half from 500 lx to 250 lx q_c changed in measurements No. 6 and 19 to unsatisfactory. In measurement No. 20 q_c did not change, because it was unsatisfactory in the preceding conditions.

The overall comparison of the complex load q_c at various values of the risk factors was carried out by means of the regression analysis. The result of this comparison is depicted in Fig. 7. In this evaluation only those measurements in which the values were under the legislation limits were taken into account. The outcomes are transformed into normalized level of noise exposure $L_{AEX,8h}$.

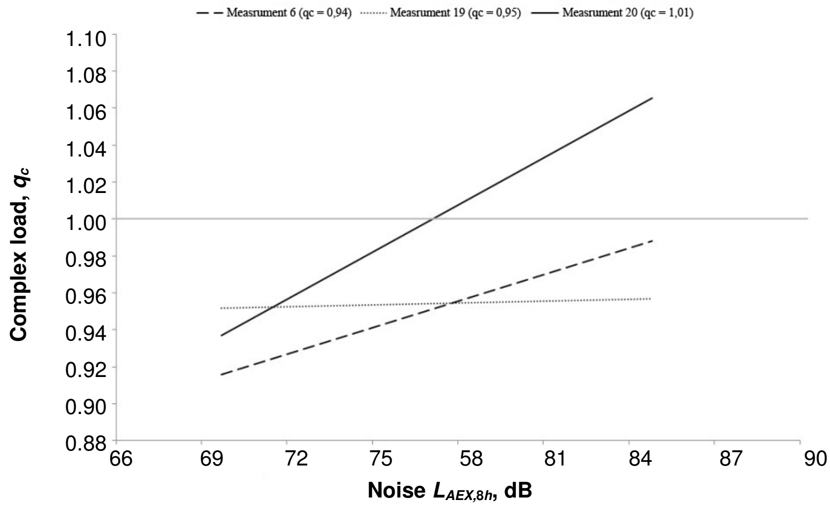

Fig. 7. **Linear regression analysis of complex load q_c**

From the regression analyses of the experiments, depicted in Fig. 6, these conclusions can be made: in case the risk factor was satisfactory (and other factors unmodified) with its increasing value the complex load parameter q_c was close to 1. In case the complex risk factor exceeds the value $q_c > 1$ the work environment will become potentially harmful. It is necessary to carry out more experiments and find the value of the complex load q_c lower than 1 to ensure correct evaluation of the work environment in case all of the factors are under the limit value.

Conclusion

From the results of the measurements and consequent experiments it is possible to state that the outcome of the complex evaluation through mathematical multivariate method is significantly biased by the set weights of the coefficients. A higher value of the weight coefficient means that the particular risk factor influences the result more and vice versa. This is the reason why the work environment was satisfactory although some factors with low weights were unsatisfactory. Therefore, it is necessary to proceed with great care when comparing pairs of factors in the Saaty matrix, from which the weights of the factors are determined.

From the current results it can be seen that setting the reference value of the complex load parameter at which the state of the work environment would damage health is very complicated and therefore it is necessary to continue with works on the complex evaluation model by including new methods. Currently, this means mainly to elaborate a new model, which would include not only objective evaluation but also subjective evaluation of the work environment.

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