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SIMULATION AS ERGONOMIC TOOL FOR EVALUATION OF ILLUMINATION QUALITY IN ENGINEERING

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Keywords: illumination, ergonomics, engineering, Dialux
Abstract: Presented article is focused on the presentation of ergonomic tool opportunities from the point of view of ergonomics which is able to quickly, reliably and appropriately evaluate the quality of illumination in the engineering. In the introduction, the article provides the overview of basic terminology from the presented issue and after that it provides the opportunity to become familiar with the software for evaluation the quality of lighting in the assembly workplace.

1 Introduction

Ergonomics as one of the youngest scientific discipline can be defined by International Ergonomics association (IEA) such as: “Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance.“ Practitioners of ergonomics and ergonomists contribute to the design and evaluation of tasks, jobs, products, environments and systems in order to make them compatible with the needs, abilities and limitations of people. Ergonomics helps harmonize things that interact with people in terms of people’s needs, abilities and limitations [10].

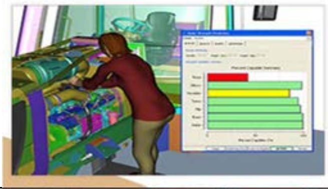
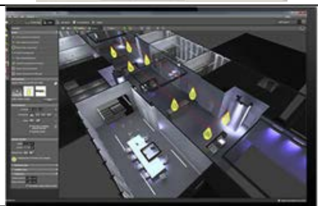
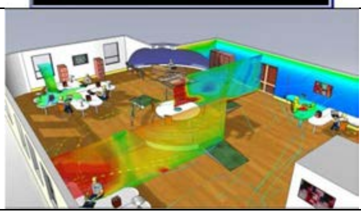
Figure 1 Interaction of ergonomics [10]

Domains of specialization within the discipline of ergonomics are broadly the following [10]:

- *Physical Ergonomics* **-** is concerned with human anatomical, anthropometric, physiological and biomechanical characteristics as they relate to physical activity.
- *Cognitive Ergonomics* **-** is concerned with mental processes, such as perception, memory, reasoning, and motor response, as they affect interactions among humans and other elements of a system.
- *Organizational Ergonomics* **-** is concerned with the optimization of sociotechnical systems, including their organizational structures, policies, and processes.

All of the above mentioned types of ergonomics can be read in the interaction with civil engineering, mining industry, general engineering etc. [6]], [[9]. Multidisciplinarity of the ergonomics is guaranteed by rapid development of ergonomic simulation tools which are focused on optimization of working positions and working activities, factors of working environment, etc. Simulaaion is the imitation of the operation of a real-world process or system over time [7]], [[8]. The following table presents several examples of simulation tool which are used in the engineering.

Table 1 The overview of the most commonly used simulation tools in engineering

Simulation software	Software image	Ergonomic system	Description
Tecnomatix Jack		human	analysis and evaluation of working positions and working activities
			simulation of exact working motions
Delmia V5 Human		human	analysis and evaluation of burden lifting, laying and carrying
			simulation of working activities
MVTA		human	ergonomic analysis of working activities and time motion studies
			analysis of position and postural analysis in time
DIALux		environment – physical factor - illumination	light – technical calculations
			calculation of indoor and exterior illumination
			calculation of illuminance level
Izofonik		environment – physical factor - noise	one – channel and two – channel measurement of noise
			calculation of noise level LA99 - LA01
FloEFD		environment – physical factor - temperature	3D simulation of heat flux and heat efficiency of buildings and working environments
			draft temperature
			predicted percent dissatisfied

As stated in the previous table, one of the possible use of simulation tools is the evaluation and optimization of working environment with a focus on physical factors, namely illumination.

2 Illumination in engineering

The illumination is possible to describe by physical quantity termed luminous intensity (E). This physical quantity describes achieved level of illumination [12]. The luminous intensity is defined as a quotient of luminous flux (ΔΦ) falling on the plane and the area (ΔS) [1]:

$$E = \frac{\Delta\Phi}{\Delta S} \quad [lx] \qquad (1)$$

, where

E – luminous intensity [lx],
ΔΦ – luminous flux [lm],
ΔS – area of fallen luminous flux [m^2]

The intensity of lighting is measured in Luxes (lx). The illumination of the plane gets smaller with the distance from the light source getting longer. It is also dependent on the incidence angle [3]. The plane of which the rays fall perpendicularly is illuminated the most. If the rays are parallel with the plane the illumination is zero. For the illumination by spot lighting photometric equation is in order [1]:

$$E = \frac{I}{r^2 . \cos\alpha} \quad [lx] \qquad (2)$$

, where

I – intensity [lm]
r – distance from the light source [m]
α – incidence angle of the rays

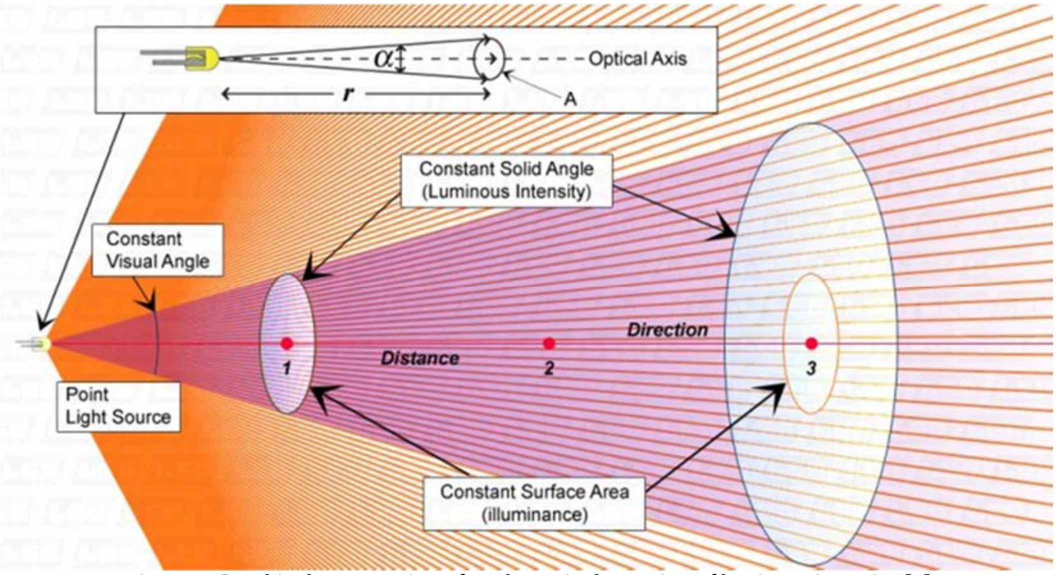


Figure 2 Graphical presentation of mathematical equation of luminous intensity [1]

The illumination of manufacturing buildings is secured by three basic electrical light sources: temperature sources, discharge tube sources or electroluminescent sources [2].

<u>*Temperature light sources*</u>

Bulbs – the least cost-effective energy light sources. They convert to light of only 3% to 8% of the incoming energy. The advantage is the low price at the expense of short-lived.

Halogen bulbs – they have a 15% greater light output than incandescent bulbs. Their lifetime period is longer and it is not depended on number of switching cycle.

<u>*Discharge tube sources*</u>

Low-pressure mercury discharge tubes – are currently the most used. It is not possible to use theirs for the exterior illumination because they unreliably ignite at a low temperature below + 7 ° C and their luminous flux decreases. The advantage of low-pressure mercury discharge tubes is high light efficiency, the low energy consumption and the long lifetime period.

Compact fluorescent tubes – are typical for household. In the industry, they are used for illumination of smaller spaces. The special types of tubes are suitable for illumination during the low external temperatures.

In the low – pressure sodium lamp the light arises in sodium vapour. The fluorescent lamps are among the most efficient light sources. They have very limited application in the industry. It can be installed only where it is not necessary to distinguish between colours.

High-pressure mercury discharge tubes – are light sources in which the major portion of the light is produced in a mercury discharge at a partial pressure in excess of 100 kPa. They are inappropriate and outdated light source.

High-pressure sodium lamp - are suitable for illumination of roads, public spaces and in the areas with the frequent fog. They are suitable only where there is the high visibility more important than the precise resolution.

High-pressure halide lamp - they have better interpretation of colour than other discharge tubes. They are used everywhere where high intensity illumination and good colour rendering.

Xenon lamp – are special type of lamp and they are often installed in dipped headlights cars.

Electroluminescent sources

LED – the light source is diode which emits the lights in the lamps. In the lamps there is usually situated the set of diodes. The advantage of LED is the long lifetime period at the expense of relatively high prices.

OLED – is used for illuminating of displays. This type amounts to a relatively small area of light output and low efficiency of about 50 lm / W.

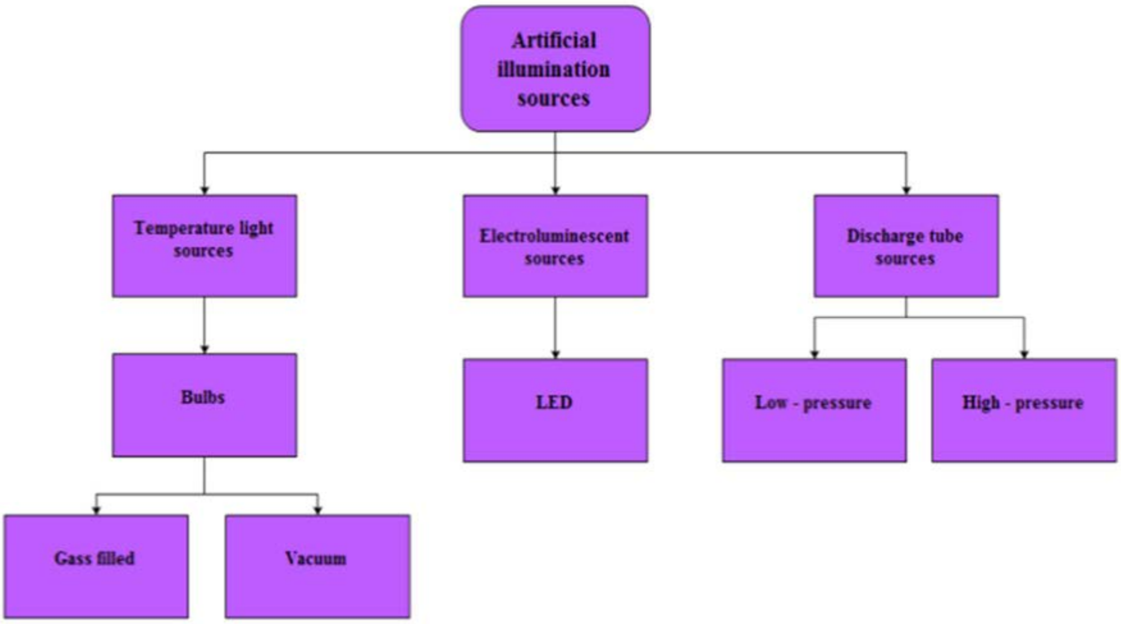


Figure 3Categorization of light sources [12]

3 Evaluation of illumination quality in the workplace using the simulation tool

The illumination quality is possible to evaluate by different simulation tool. The most frequent used software for evaluation of illumination in the industry is simulative light – technical tool Dialux evo. On the basis of simple user interface, it provides the creation of thorough suggestions of interior and exterior lighting system [11].

The advantage of this simulation tool is simple conception of user interface with extra speed dial right start-up splash screen, which offers access to the home menu in three sections - create a new project, edit existing project, other topics. After the chosen alternative it is possible to begin with the creation or modification of illumination system model using the main toolbar which includes options for working with modelling, supplementing and defining lighting system with a choice of lighting manufacturer's catalogues.

The newest software platform has the possibility of assigning light from various global manufacturers such as Osram, Panasonic, Philips, LG Electronics, etc. The available manufacturers for their resources regularly perform the tests and their results published in electronic form via the Internet, ensuring the timeliness and accuracy of the light sources used. They provide important data about the character of suggested illumination including the important parameters of comprehensive luminous system.

It was selected the assembly workplace (15 000 x 7 000 x 3 200) for the production of stainless banisters for the model creation. The wall thickness is 150 mm and the evaluating plane is of 0.85 meters. The following figure presents an overview of workplace for operation with the associated lighting.

In the evaluated workplaces there are six pieces of Phillips lights with the characteristics shown in the figure 5.

Figure 4 Evaluated workplace

Quantity	Luminaire (Luminous emittance)
6	Philips Lighting TBH375 2xTL5-49W HFP_452 Luminous emittance 1 Fitting: 2xTL5-49W/452 Light output ratio: 81.83% Lamp luminous flux: 7400 lm Luminaire luminous flux: 6055 lm Power: 108.0 W Light yield: 56.1 lm/W Colour temperature: 3000 K Colour rendering index: 100

Total lamp luminous flux: 44400 lm, Total luminaire luminous flux: 36330 lm, Total Load: 648.0 W, Light yield: 56.1 lm/W

Figure 5 Specifications of lights – output from Dialux software

It is also 6 pieces of windows on the upper part of the end wall of the workplace (comprehensive illumination). The following figures present the disposal workplace layout and assembled model in the simulation software Dialux Evo.

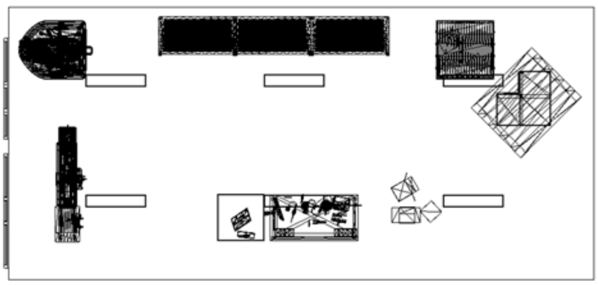


Figure 6 Workplace layout

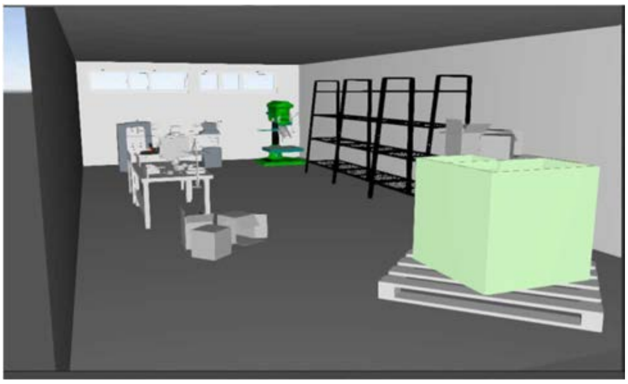
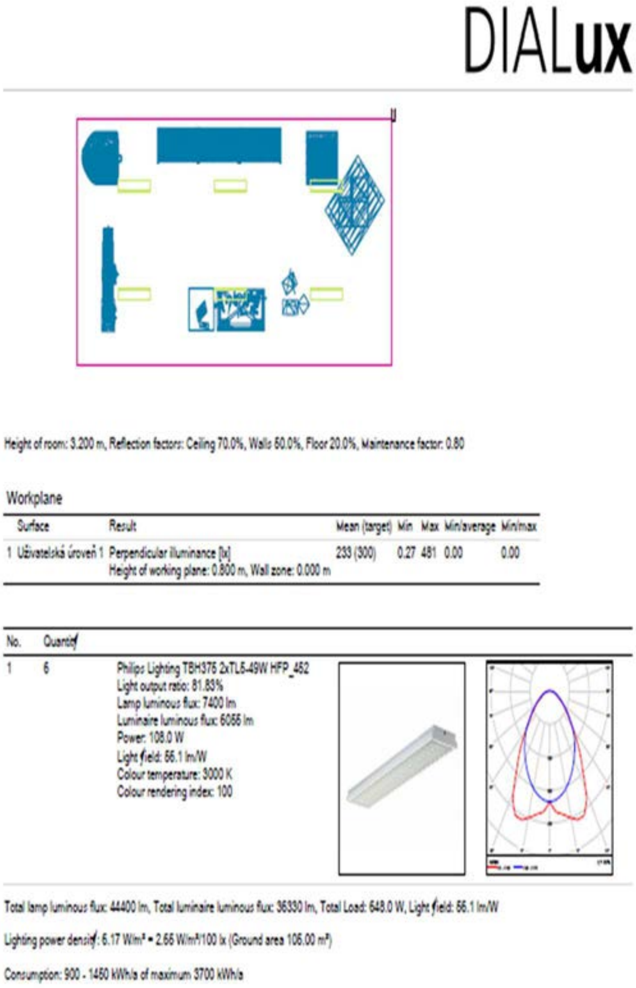


Figure 7 Model of workplace – Dialux evo

The target of model creation and realization of illumination simulation is getting the light – technical data which is possible to improve or optimize by modification of model or modification of illumination. After the achievement of necessary data, it is possible to interpret the results obtained in graphical and tabular form. From the graphical interpretation of results it is possible to state that the actual illumination of working environment is not suitable. This statement is confirmed by numerical results which are presented in the figure under the text.

Figure 8 Isophote course 2D (left) a 3D (right)



Height of room: 3.200 m, Reflection factors: Ceiling 70.0%, Walls 50.0%, Floor 20.0%, Maintenance factor: 0.80

Workplane

	Surface	Result	Mean (target)	Min	Max	Min/average	Min/max
1	Uživatelská úroveň 1	Perpendicular illuminance [lx] Height of working plane: 0.800 m, Wall zone: 0.000 m	233 (300)	0.27	481	0.00	0.00

No.	Quantity	
1	6	Philips Lighting TBH376 2xTL5-49W HFP_452 Light output ratio: 81.83% Lamp luminous flux: 7400 lm Luminaire luminous flux: 6056 lm Power: 108.0 W Light yield: 56.1 lm/W Colour temperature: 3000 K Colour rendering index: 100

Total lamp luminous flux: 44400 lm, Total luminaire luminous flux: 36330 lm, Total Load: 648.0 W, Light yield: 56.1 lm/W

Lighting power density: 6.17 W/m² = 2.65 W/m²/100 lx (Ground area 105.00 m²)

Consumption: 900 - 1450 kWh/a of maximum 3700 kWh/a

Figure 9 Numerical evaluation of illumination quality

The results of the simulation confirm that the maximum value reached workplace lighting is 482 lux, which is far from sufficient. Therefore, it is necessary to make amendments and additions to the lighting holes, supplementing or replacing lamps. After implementation of optimization is required to perform the simulation again and compare the results obtained.

Conclusions

Simulation is a key technology of industrial engineering from the various reasons - increasing the complexity of issues that need to be addressed today, but also by computer programs to simulate descended from "sterile" data centres to design offices and production workshops. [4],[5] One of these problems is the provision of well-being in the workplace in terms of ergonomics, evaluation burden and physical factors of the working environment. The subject of this article was to introduce the possibility of simulation tools in terms of ergonomics, which can quickly reliably and adequately assess the quality of lighting in the workplace. On the basis of results, the individual user can evaluate the status of work and propose adequate solutions to the finish. Then, the optimized solution is again carrying out simulation and they are discussed the achieved results. In conclusion, the proper selection and effective use of simulation tools requires many experts and knowledge by means of which subsequently formed the correct simulation models. The benefits of simulation tools (ergonomic planning, management etc.) if used correctly they provide an added value to the company.

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INFLUENCE OF PHYSICAL FACTORS OF WORKING ENVIRONMENT ON WORKER'S PERFORMANCE FROM ERGONOMIC POINT OF VIEW

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Keywords: physical factors, working environment, noise, vibration, lighting, microclimate
Abstract: The article deals with the optimization of logistic flow of selected company in the area of software module Process Simulate. The aim is to design a logistics flow, which will reduce machine downtime, number of workers during the operation of CNC centres or achievement the elimination of redundant manipulation steps of direct staff. Modelling and simulation of workplace in a software module Process Simulate enables to rationalize it in virtual environment, which will contribute to cost savings that are expended in the process of direct implementation of the proposals in practice.

1 Introduction

The aim of company is to maximize quantity and quality of production and remove barriers that defend it. The best example of these barriers are: excessive noise of environment, bad working desk, poor lighting, but also air current or odor. All these factors are called working conditions. It is true that many working conditions are regulated by legislation, but there are also factors which are not regulated by legislation or are difficult to measure.

The aim of this paper is to explain and process work environment in relation to physical factors and ergonomics. These factors that are often overlooked, may be the etiological agens and a source of personal employee disaffection.

1.1 Working environment

Working environment is a set of physical, chemical, biological, socio-psychological and other factors, that affects on employees. Within physical conditions, most authors focus on microclimate of working environment (temperature, humidity and air flow in the workplace), workplace lighting, noise and vibration in the workplace, colorful interior design, and air pollution.

1.1.1 Physical factors of working environment

Work is performed in a specific physical environment. Physical factors consist of following factors: microclimate conditions that affect thermal comfort of humans, noise, vibration and lighting.

Noise:

Noise is defined as all sound in the workplace, either wanted or unwanted and is one of the most common Occupational Health and Safety (OHS) hazards and is found in many different environment. Noise or sound is created by alternate compression and decompression of particles of the air. This causes the air pressure to fall and rise in the form of waves. Frequency (pitch) and intensity (loudness) are the two characteristics of sound [4].

The loudness of sound is measured in units called decibels. Sound pressure level (SPL) is the basic measure of the magnitude of the acoustical vibrations of the air that make up sound. Because the sound pressure range that human listeners can detect is very wide, (10-5 to 102 Pascal (Pa)), these levels are measured on a logarithmic scale with units of decibels. For example, usual conversation is approximately 60 decibels, the humming of a refrigerator is 40 decibels and city traffic noise can be 80 decibels [4], [10].

Noise can be expressed also mathematically. Sound is a stimulus, and it reaches the ear as part of the energy of the audibility field which is transmitted in it as longitudinal vibration. Therefore, in the medium of density p it spreads by phase speed - alleviation and densification determined by the changes in pressure Δp, and the air temperature is expressed in °C.

Phase of vibration speed $c = f \times \lambda$,
λ - vibration wavelength,
f- frequency.

$$v = 332^{ns^{-1}} \sqrt{1 + \frac{t}{273{,}15}} \quad (1)$$

Having expressed the motion of the audibility field in the presented manner, it remains only to explain the ways in which men receive sound as stimulus, i. e. information. It is explained by the Weber-Fechner law of relations between stimulus and sense, which says, in fact, that the change of sense Y is proportional to the change in stimulus X, which can again be expressed mathematically:

dy=KdY/X (2)

Y=lnX+C (3)

In case of sound, stimulus X is proportional to the density of the power of the audibility field and is measured in [W/m2]. If we replace in the equation Y = In X+ C natural logarithm by the decimal one, and if we determine the constant C, so that the sense has the value of 0, and the sensitivity threshold of the ears W_0 is equal to the density of the sound intensity, we obtain:

$$Y = \log\left(\frac{W}{W_0}\right) \quad (4)$$

For the use in practice, where the industrial production has been intensified, and the work productivity is strong, a 10 times reduced unit is used, called dB (decibel), and the sound intensity is:

$$L = 10\log\left(\frac{W}{W_0}\right) dB(A) \quad (5)$$

$$W_0 = 10^{-12} W/m^2 \quad (6)$$

The consideration does not include the frequency. Since it is known that human ear recognises different 254 frequencies, the gauges are fitted with the frequency filter («filter A»). It should certainly be noted that in case of double multiplication of the noise source, i. e. noise for the new source, the level of noise increases by 3 dB, independent of the level of the first source.

Mathematically:

$$L_1 = 10\log\left(\frac{W_1}{W_0}\right) dB(A) \quad (7)$$

$$L_2 = 10\log\left(2\frac{W_1}{W_0}\right) = 10\log\left(\frac{W_1}{W_0}\right) + 10\log 2 \quad (8)$$
$$= L_1 + 3dB(A)$$

Thus, we can calculate that the increase of sound by 10 times increases the initial intensity by 10 dB(A), and by 20 dB(A) for a lOO-times increase. In case of different sources of noise, the intensities of the audibility field have to be added, and the resulting intensity is expressed by the expression:

$$L = 10\log \sum_{i=1}^{n} 10^{Li/10} \quad (9)$$

In alternate noise, adequate level L_{eg} is the constant intensity that would result in energy load on the worker in the production, as if being continuously exposed to noise:

$$L_{eg} = 10\log \frac{1}{t_0} \int_0^{t_0} x10^{L(t)} x10^{dt} \quad (10)$$

t0 - time duration of measuring the intensity,
L(t) - function of time.
Exposure to noise at work [10]:

The noise is most common negative factor in the work environment, while only in Slovakia in 2008 were more than 88 300 employees of various economic sectors exposed to excessive noise. Despite the generally accepted view, that threaten are only (or especially) employees of industries, there is number of other professions that may be exposed to noise levels exceeding the limits.

Slovakia According to the first candidate countries survey on working conditions in 2001, about 20 % of workers in Slovakia were exposed to noise so loud that they had to raise their voice to talk all of the time or almost all the time. On the whole, approximately 45 % of workers were — to various degrees — exposed to noise at work. According to the data of the Institute of Public Health of the Slovak Republic, the number of workers exposed to noise decreased in 2005–2010 by about 15 %, but after this period there have been no significant changes in the percentage of workers exposed. About 89 000 workers were exposed to noise at work in 2013. The percentage of women exposed to noise decreased from 22 % in 2005 to about 18 % in 2015.

In Slovakia there is a joint legal regulation for both outdoor and indoor noise limits (Figure 1). This regulation is incorporated in the Ordinance of the Ministry of Health No. 549/2007 Coll. on Details of Permissible Values of Noise, Infrasound and Vibrations.

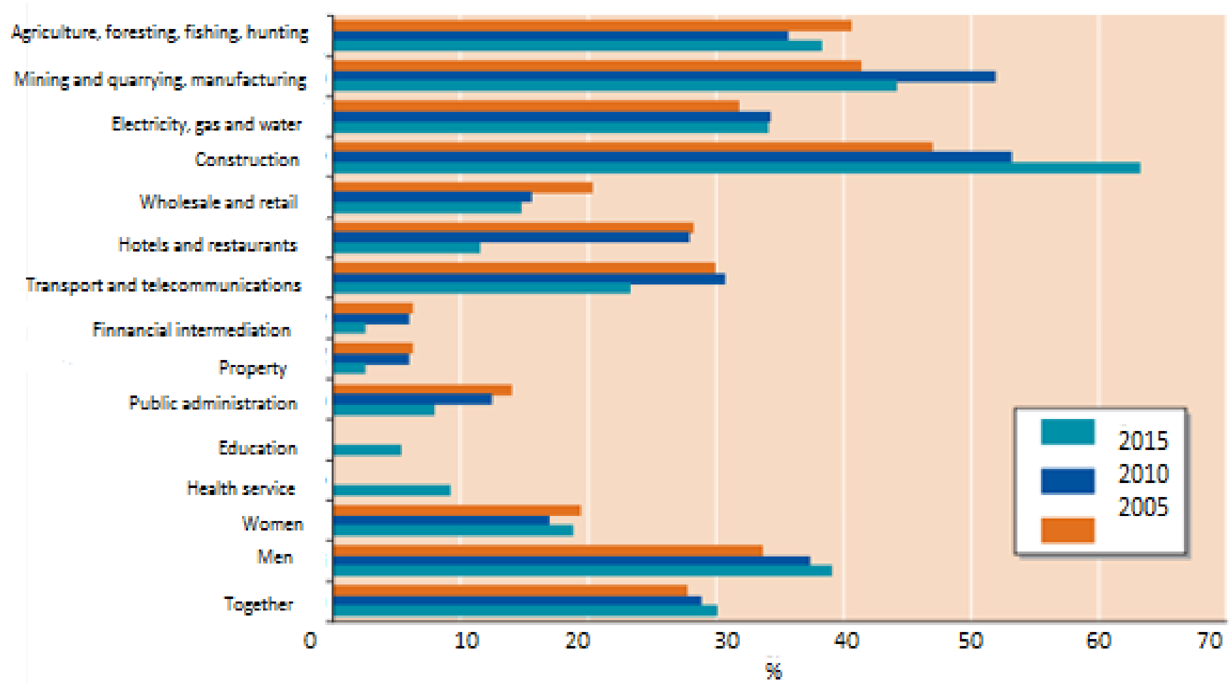

Figure 1 Percentage of workers exposed to noise for at least quarter of working time [10]

Lighting:

The Illuminating Engineering Society of North America (IESNA) defines light as "radiant energy that is capable of exciting the retina and producing a visual sensation." Light, therefore, cannot be separately described in terms of radiant energy or of visual sensation but is a combination of the two (Figure 2) [17].

Light is that part of the electromagnetic spectrum that is perceived by our eyes. The wavelength range is between 380 and 780 nm.

Light has a triple effect:

Light for *visual* functions: Illumination of task area in conformity with relevant standards, Glare-free and convenient

Light creating *biological* effects: Supporting people's circadian rhythm, Stimulating or relaxing

Light for *emotional* perception: Lighting enhancing architecture, Creating scenes and effects

Basic parameters used in lighting:

Luminous flux, Luminous intensity, Illuminance, Luminance.

Luminous flux:

The luminous flux describes the quantity of light emitted by a light source. The luminous efficiency is the ratio of the luminous flux to the electrical power consumed (lm/W). It is a measure of a light source's economic efficiency [2].

Luminous intensity:

The luminous intensity describes the quantity of light that is radiated in a parti - cular direction. This is a useful measurement for directive lighting elements such as reflectors. It is represented by the luminous intensity distribution curve (LDC).

Illuminance:

Illuminance describes the quantity of lumi - nous flux falling on a surface. It decreases by the square of the distance (inverse square law). Relevant standards specify the required illuminance (e.g. EN 12464 "Lighting of indoor workplaces").

$$E(lx) = \frac{lu\min ousflux\ (lm)}{area\ (m^2)} \tag{11}$$

Luminance:

Luminance is the only basic lighting parameter that is perceived by the eye. It specifies the brightness of a surface and is essentially dependent on its reflectance (finish and colour).

All principal Lighting associations and Societies of the world agreed about optimal lighting conditions for various areas, so finally international standards have been made. Standards are collected within European norms, which can be purchased from National Standardization Institutes or from the central European Institution for Standardization [2].

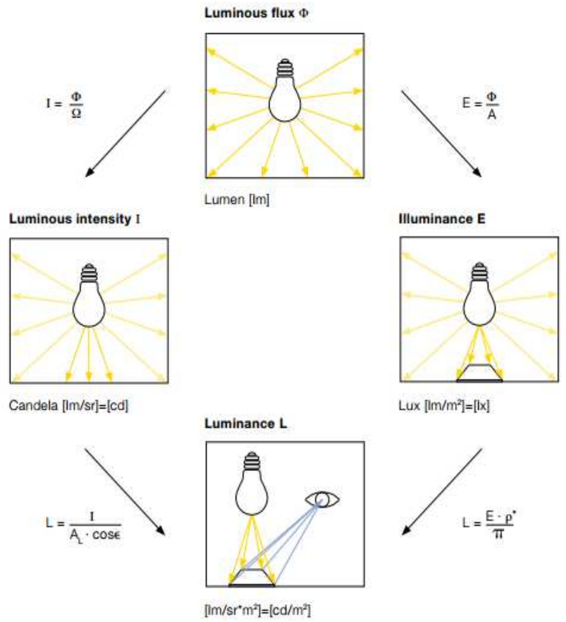

Figure 2 Basic parameters used in lighting [17]

Microclimate:

Microclimatic parameters: Microclimatic parameters (or conditions) of the work environment also known as thermal-moisture parameters are determined by temperature, relative humidity and airflow. These physical quantities define subjective well-being (comfort) or ill-being (discomfort). In extreme cases can be considered as pollutants with adverse effects on human health [1].

Temperature: Particular type of working class has got determined the optimal microclimate conditions, depending on body heat production affected by intensity of employee's activity. The total energy expenditure assigns the individual work activities to the working classes: 1a (sitting at work, administration), 1b (standing at work), 1c (such us mechanics work, work in the steel industry), 2 (such as operating machines, work in the building industry), 3 and 4 (intensive and very intensive work).

Table 1 The optimal and permissible temperature for some working class [1]

Working class	Temperature (°C)			
	Optimal temperature		Permissible temperature	
	Warm season	Cold season	Warm season	Cold season
1a	21-25	20-23	20-28	20-26
1b	20-24	18-21	18-26	17-24
1c	18-22	15-19	16-25	13-22
2	16-19	12-17	12-24	10-20
3	The value does not determine			
4				

Range of optimal values of microclimatic conditions in the working environment is set for a warm period (average daily outdoor temperature 13°C and more) and winter season (decrease of the average daily temperature for two consecutive days below 13°C). The optimal and permissible temperatures for warm and cold season of the year are in the Table 1 (Slovak Directive No. 544/2007). In case of the workplace with long-term nature where it is impossible to provide optimal conditions, the employer is required to ensure compliance with permissible microclimatic conditions. Exceptions are in need of special workplaces where the burden of heat or cold is impossible to be removed due to various technological reasons [1].

Humidity: Humidity in the working environment is a specific factor. The specificity of factor is mainly in the fact that unlike the temperature, this can be subjectively very difficult to perceive and then evaluated. The human body can have an adverse effect on the decrease in humidity on the level of 20% mainly in winter (due to heating) and the humidity in excess of the 60% in other seasons [4].

Heat production of man increases with the physical activity. The main resources are mainly muscle groups that produce net metabolic heat. Basal metabolic heat is added to net metabolic heat, which is produces basically on biological processes in the human body. Metabolic heat q_m is given by :

$$q_m = M - W = q_{m,b} + q_{m,\,net} \tag{12}$$

M is the total metabolic heat production in $W.m^{-2}$
W is job performance (mechanical work) in $W.m^{-2}$
$q_{m,b}$ is basal metabolic heat in $W.m^{-2}$
$q_{m,b}$ is net metabolic heat in $W.m^{-2}$

European standard establishes the metabolic heat unit met. Met represents thermal output of sitting man. (1 met = 58,2 $W.m^{-2}$).

Energy expenditure is determined by measuring the oxygen consumption according to reference tables or calculation.

Thermoregulatory process of heat exchange between human body and the environment is given by equation of heat balance

$$S = Q_{core} + Q_{sk} \tag{13}$$

S is accumulated heat in body in $W.m^{-2}$
Q_{core}= (M-W) + (C_{res}+E_{res})+q_{tr}+q_a is heat flow form the core of body through the skin in$W.m^{-2}$
Q_{sk}= C+R+K+E_{sk} is a heat flow from the body surface to the environment in $W.m^{-2}$
where:
(M - W) is the metabolic heat in $W.m^{-2}$
C_{res}+E_{res} is respiratory heat (conventional resp. heat in C_{res}+ evaporative heat E_{res} in $W.m^{-2}$
q_{tr} is thermoregulatory heat
q_a is adaptation heat in $W.m^{-2}$
C heat is transferred by convection in $W.m^{-2}$
R heat is transferred by radiation in $W.m^{-2}$
K is heat tranferred by convection in $W.m^{-2}$

E_{sk} is heat transferred by evaporation or condensation in W.m^{-2}

Vibration:

Vibrations are mechanical oscillations which pose a hazard to human health when acting continuously on the hand-arm system (hand-arm vibrations) or on the entire body (whole-body vibrations). Vibrations may cause blood circulation problems, bone or joint disorders, neurological or muscular conditions, back pain, or damage to the spinal column.

Vibration is often called a vector quantity, which means that the vibratory motion has both a negative effect in of itself and a magnitude or intensity component [16].

Generally, two forms of exposure may be distinguished: whole-body vibration (WBV), which is transmitted by mobile or fixed machines where the operator is standing or seated, and hand-arm vibration (HAV), which is transmitted by hand-held or guided tools. In simple terms, vibration is defined by its magnitude (traditionally described using acceleration, expressed in m/s²) and frequency (the number of times per second the vibrating body moves back and forth, expressed in cycles per second, or hertz (Hz)). The risk of damage is not equal at all frequencies; therefore, when calculating exposure, a frequency weighting is used. Furthermore, vibration must be evaluated in three axes (vertical, fore and aft, and lateral axes in the case of WBV). From each vibration axis a frequency-weighted root-mean-square average acceleration is measured. This is referred to as *ahw*. Since the risk of damage is not equal in all axes, a multiplying factor must be applied to the frequency-weighted vibration values. In the case of WBV, the acceleration values for the two lateral axes (x and y) are multiplied by 1.4, whereas for the vertical (z axis) they are multiplied by 1.0. In the case of HAV no multiplying factors are used. In the case of WBV, the equivalent acceleration is obtained from the highest of three orthogonal axes' values (1.4*awx* 1.4*awy* or *awz*) that are used for the exposure assessment. HAV risk, on the other hand, is based on the frequency-weighted acceleration total value *ahv* given by the root sum of squares of the frequency-weighted acceleration from the three orthogonal axes, *x*, *y* and *z* [16]:

$$a_{hv} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2} \tag{14}$$

The vibration directive defines the daily exposure, A(8), as:

HAV: the equivalent continuous acceleration, normalised to an eight-hour day; the A(8) value is based on root-mean-square averaging of the acceleration signal and has units of m/s²;

$$A(8) = a_{hv}\sqrt{\frac{T}{T_0}} \tag{15}$$

where T is the daily duration of exposure to the vibration magnitude a_{hv} and T_0 is the reference duration of eight hours.

WBV: the equivalent continuous acceleration over an eight-hour period, calculated as the highest (*rms*) value, or the highest vibration dose value (VDV) of the frequency-weighted accelerations, determined on three orthogonal axes (1.4*awx*, 1.4*awy*, *awz* for a seated or standing worker). The directive sets exposure action values, above which it requires employers to control the vibration risks to their workforce, and exposure limit values, above which workers shall not be exposed:

- a daily exposure action value of 0.5 m/s² (WBV) or 2.5 m/s² (HAV);
- a daily exposure limit value of 1.15 m/s² (WBV) or 5 m/s² (HAV).

Human exposure to WBV should be evaluated using the method defined in International Standard ISO 2631-1:1997, together with the detailed practical guidance on using the method for measurement of vibration at the workplace, which is given in EN 14253:2003. In the case of human exposure to HAV, the method that should be used is defined in European Standard EN ISO 5349-1:2001, together with the detailed practical guidance on using the method for measurement of vibration at the workplace, which is set out in EN ISO 5349-2:2001 [16].

2 Ergonomic analysis in the digital environment

Most companies looking for savings in purchased materials, overheads, energy. They are looking for ways to achieve these savings. One way is to use software products for the creation of virtual reality and optimization of the current state of business processes without the cost of direct implementation of suggestions for improvement.

The principle of modelling in Tx Jack and Process Simulate Human is demanding in terms of modelling machines, equipment, vehicles, etc. To create a working environment, it is appropriate to use other softwares, which creates a working environment easier.

Software Tx Jack is compatible with the software, which can create a virtual environment of a particular workplace or halls such as CAD. Thus created environment can be imported into the working environment of Tx Jack and then place a concrete worker in it with concrete working activities

Main function of Tx Jack and Process Simulate Human are therefore creating a human being with accurate anthropometric parameters, simulation of movements (individual body parts) and determine the burden caused by work´s activities and work´s environment. If it is not necessary to determine the physical stress on the particular operator, but it is necessary to dimension the workplace in general, it is possible to use the database ANSUR (Survey

Volume: 2 2016 Issue: 3 Pages: 9-16 ISSN 1339-9640

of U.S.Army) which contains data collected realization of a survey personnel of military of USS in 1988.

Siemens Tecnomatix software package has several modules for each area of usage. For modelling and simulation of the impact of the working environment on staff, creating 3D models of working environment, workers and their activities and detect physical stress through a specific predefined base of ergonomic analysis can be used two modules [3]:

- **Tx Jack/Jill** - it's a 3D simulation tool for evaluating of physical stress during the manual work activities, this is the instrument through which it is possible design workplace in the virtual environment and simulate various solutions that meet ergonomic standards without investing in equipment and technology. Digital human model in this program is a real biomechanical properties of natural motion and joint rang - taken from NASA studies.
- **Process Simulate Human** - allows users to verify the design of work stations, verify the achievement of the required safety of the individual parts of a product. The module offers powerful features for analysing and optimizing the ergonomics of human activity, thereby providing an ergonomic and safe production process according to industry standards. Using simulation tool of human activity, the user can perform realistic simulation of the human tasks and optimize process times of the production cycle according to the standards of ergonomic.

In the following figures (Figure 3 and Figure 4) there is a short comparison between human operation created in the Process Simulate environment and Jack module. It is shown only a basic operation – walking, where you can see the differences of creating the operation and also the graphical windows displaying the software environment.

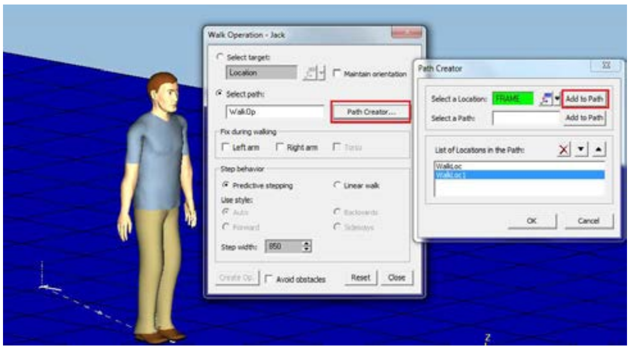

Figure 3 Tecnomatix Process Simulate - Walk creator

In the Process Simulate module, you need to choose the requested human model in the graphics window and selecting Walk Creator - from the main Human menu. In the window Operation Walk - Jack there is a possibility to propose the walk operation by positions - either by entering the human target positions (Select Target), where human has to move, or selecting Path Creator and then entering a path along which go human model to the desired destination.

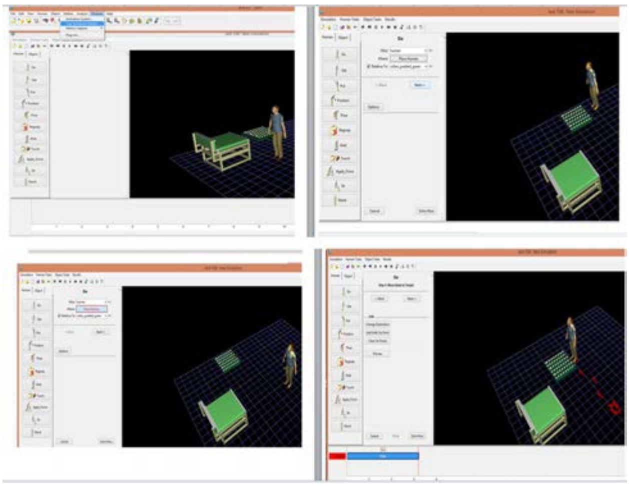

Figure 4 Tecnomatix Jack - Task Animation Builder

It needs to click in the main menu Modules Task Simulation Builder. It opens a working environment in which it is possible to create human movements that are in the menu - eg. Go, Get, Put, position, pose, touch, regrasp ATC.

2.1 Jack Task Analysis Toolkit

Task Analysis Toolkit (TAT) assessment tools are linked directly to the human figure, minimizing user inputs and standardizing assessment results between users. TAT tools can be run interactively, enabling real time results during animations and motion capture sessions. TAT tools are based on recognized data sources endorsed by the ergonomics community • Analysis reports are available for TAT tools, enhancing communication of results. TAT includes simplified screening tools, as well as complex quantitative analysis options, facilitating easy use and interpretation. Tecnomatix Jack module has many tools for ergonomic measurement (Figure 5):

- NIOSH (National Institute for Occupational Safety and Health)
- OWAS (Ovako working posture analysis)
- MTM (Methods-Time Measurement)
- RULA (Rapid upper limb assessment)
- SSP (Static strength prediction)
- And many other...

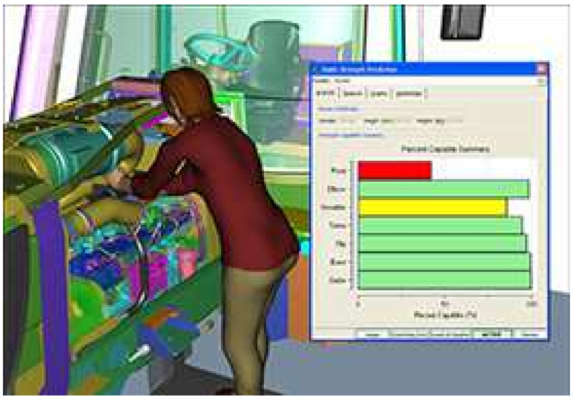

Figure 5 Tecnomatix Jack - Task Analysis Toolkit

Conclusions

Violation of ergonomic principles leads to the health damage of workers. Working in wrong position and performing unnatural movements can lead to incapacity to work what represents financial losses for employer. Legislation provide that the employer must create suitable working conditions for its employees. The attention should be paid to factors affecting the long-term physical and psychological burden on workers, because the workplace is characterized by physical load and work done in unsuitable environments.

Physical factors of working environment must be measured by appropriate methods and measuring devices, that are defined in the relevant laws and regulations. Subsequently, the measured values are compared with the requirements laid down in legislation. Nowadays, this form of evaluation is preferred, but it does not bargain for reciprocal action of parameters in working process. Therefore, the scientific discipline called ergonomics was created. The main goal is to bring a systemic view of the relationship created between man and the working environment, including work tools. If the measured value exceeds the value of certain factors that are standardized, it is important to ensure the elimination of the factor applying different measures.

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PRINCIPLE OF INVENTION GENERATING FOR THE INNOVATION WITHIN THE OPEN INNOVAITON SYSTEM

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Keywords: innovations, open innovation system, invention, sources of inventions
Abstract: According to the issue of invention sources for innovation nowadays the company gets the ideas from internal as well as external environment. But in addition there is also a specific group of inventions with origin in sources cooperation. They come from corporate innovative machine and in this context of cooperation they are difficult to classify into group of external or internal sources. Different available tools and techniques for corporate innovation machine support can help to develop it and to keep it running. The corporate innovation machine can run based on basic principles of Idea management, Idea Generator and more other tools and techniques, which use for implementation of innovation strategy planning can depends on internal and external company sources.

1 Introduction

The systematic, goal orientation and mainly systematically planning of innovation is necessary for achieving the long-term success of business activity. The innovations come from the ideas which were developed and subsequently implemented [1]. All innovation then come from innovation ideas and generating these ideas is the first phase of any innovation process. The ideas are developed and combined in different way in time. For the purpose of successful innovation the companies should have the sustainable flow of ideas [2]. The innovation processes are the specific tools of business activity, which add to the sources new ability of wealth creation. In essence the innovation creates these sources as well as anything as „source“ does not exist, until the human find the purpose of use and add an economic value to the source [3].

2 Invention sources in the traditional point of view

It is appropriate to have systematically processed the innovation strategy of the company in the form of planned innovation process for fulfilment of the company strategy through methods and techniques supporting innovation strategy. In the case of planned innovation process supporting the innovation strategy the company creates so-called *corporate innovation machine* [4].

The driving force of corporate innovation machine must be a management of the company. It should clearly state the innovation strategy and follow it as first, but also create a corporate culture which motivates the employees to think creatively and to contribute suggestions for company development. The management should actively support them, for example by creating time and space to meet and fulfil their ideas and needs. When thus organised *Power by management* the corporate innovation machine works as „perpetum mobile“ in the way of ideas generation, analysis and implementation. The corporate innovation machine that is built on the positive results of innovation process supports new ideas creation – inventions and subsequently innovation. They can follow the original ones, upgrade unfeasible ones, more precisely evaluate quality of new inventions based on previous experience or create entirely new invention and innovation.

Different available tools and techniques for corporate innovation machine support can help to develop it and to keep it running. The corporate innovation machine can run based on basic principles of Idea management, Idea Generator and more other tools and techniques, which use for implementation of innovation strategy planning can depends on internal and external company sources.

Basically sources of innovation ideas can be divided into internal and external sources. That kind of classification derives from the origin of ideas himself – they can come from inside of the company as well as external environment of the company. The companies can strengthen its base of innovation ideas in addition to the implementation of internal ideas from research and development by importing, developing, analyzing and adapting the ideas from the environment to the company conditions [5].

The important internal innovation ideas source is employees, the external are all sources, which originate out of the company and are available also to another subjects except for the company [6].

Nowadays the increasing importance of external sources of innovation ideas is highlighted since the companies are more and more relying on new technological knowledge when generating the ideas. They are obtained not only by internal departments of research and development but also by the interaction of the company and external sources of innovation ideas [7, 8]. That is confirmed also by Kováč [9] according to who the practise shows that 80 % of successful innovation does not come from own sources, but were initiated from external information sources. Therefore the systematic work with information source is important for every innovation oriented company, which must purposefully access to the innovation ideas generating [10].

Important sources of innovation ideas are the environment changes as unexpectedness of events, discrepancy of events, process needs, and changes in the structure of industry and services, demographic changes, changes of viewing and new knowledge [9, 11]. Important external sources of innovation ideas are scientific, technical and commercial publications, patents and licenses, exhibitions and internet. Internal sources represent research and development, marketing surveys and suggestions of own employees, suppliers and customers [9].

The innovation necessity arises when current programme in the medium and long term horizon is not sufficient to achieve business objectives and sustain competitive advantages [6]. Product innovation should contribute to eliminate the risks and weaknesses as well as opportunities and strengths of the company. The innovation necessity changes in time during the innovation process and so we consider it as dynamic. To avoid the investments to poor innovation opportunity it is necessary with increasing concretization of product invention to constantly question it in terms of whether to continue or not until the creation of innovation driving corporate innovation machine. Invention means synthesis of recognition of the potential customers' needs and the way to meet this need by a new solution.

3 Inventions sources for innovation creation within the open innovation system

According to the theoretical knowledge and approach of mentioned authors [5, 6, 7, 8, 9, 11], the ideas (inventions) sources are classified as internal and external sources. According to the observation we can conclude that actually there is a problem to include some inventions sources into the group of the internal or external sources. Therefore the aim of the paper is to define the inventions sources for innovation, in terms of theoretical understanding as they are used today in the business environment, based on the principle of open innovation system.

Basically, in the traditional point of view, the sources of innovation ideas can be divided into internal and external sources.

As internal sources are understood suggestions from employees, which we obtain by use of various tools for generating ideas, such as:

- Idea Management - purposeful systematic process of creating, capturing and evaluating ideas and then implementing the best ideas into practice.
- Idea Generator – generating of new ideas, e.g. inventions, wherein the innovation is implemented invention generated by creativity in order to generate values of a quantitative or qualitative nature of positive effects,
- SkunkWorks – free organized research unit within the company that deals with research innovation,
- Creative point – point where not-conventional, but many problems-solving ideas and invention are created mainly by informal conversation,
- And more other tools use in connection with employees in internal environment of the company.

External sources come from company environment and are represents by:

- Customer suggestions,
- Competitors,
- Scientific research institutions and so on.

The intensity, structure and aggressive competitors' behaviour determine competitive and innovation pressure on the market what causes innovation necessity. When identifying the competitors it is necessary to conclude except of publicly active competitors also those who are not yet on the market or are not engaged in the tender of the industry, but they may have a strategy and inventions potential. As well as the innovation necessity from the target customer and market is related to relatively low risk of failure. The problem here lies in the recognition of gradually manifested offer niche, representing space for inventions and innovation creation. Changing environment conditions influence the other drivers of innovation conditioned by inventions sources as companies, competitors, customers, trade, political and legislative changes or ecological changes of conditions [3, 6, 12].

Following on mentioned facts, actually internal company innovation impulses (inventions) is not possible to derive only from own technological positions, product portfolio and source changes, but also from external sources. The method *Fits and Misfits* signalizes innovation necessity in production programme and strategic goals of the company regarding the environment conditions [13].

The open innovation system helps to understand how to implement innovation strategy to the company effectively. Currently in practise within this open innovation system we obtain invention sources from a majority of sources, which are interconnected and collaborating. That kind of sources obtained by collaboration is then difficult to classify to a category of internal or external invention sources, see Figure 1. They are related to the open innovation system, which is based on the use of external research capacities in cooperation with its corporate internal capacity or orientation to search only certain elements of the innovation process in the external environment [3].

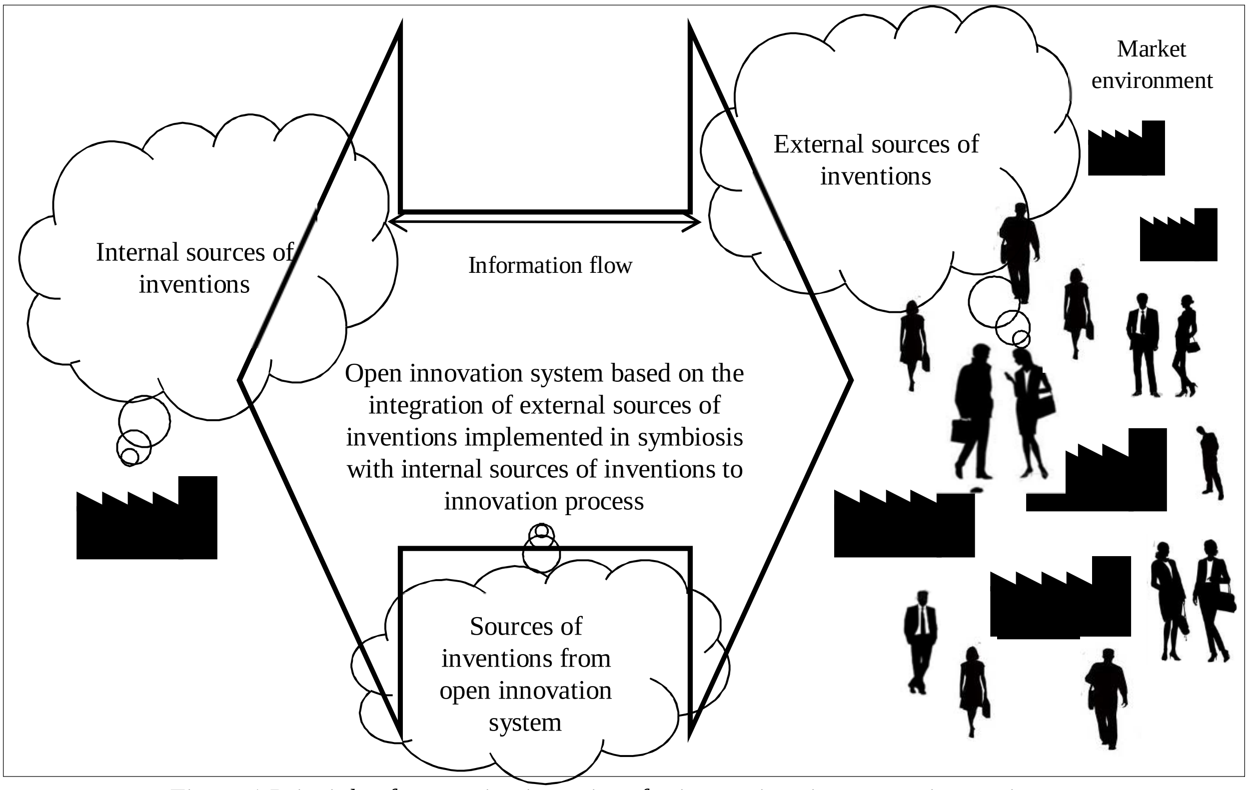

Figure 1 Principle of generating inventions for innovations in an open innovation system

The open approach to the innovation process facilitates innovation flow penetration in a companies or countries. Innovation platforms of information and communication technologies, which stimulate innovation, actually support that [15, 16].

Invention sources from open innovation system are based on the integration of external sources of inventions based on collaboration and synergic effect for all interested subjects in innovation process. They are implemented in symbiosis with internal sources of inventions to innovation process. These sources need specific approach, when market demands are systematically obtained and evaluated to reduce product declines. Particularly important is customer integration into process of new product ideas obtaining. The basics of external sources integration in that way is consumer integration enabling knowledge transfer and extending options of market research. While process, marketing and organizational innovations are focused on internal company's factors such as cost, quality, time etc., on the contrary product innovations are focused on value-creating process in relation to the market for providing new performance.

Only formal receiving and analysing of information coming to the company is not sufficient for active integration of external sources into innovation process and their realisation in symbioses with internal sources. The company should mainly focus on information obtained by direct contacts and cooperation of company and external subjects. The inventions are then becoming implicit and different from explicit knowledge that are easy structured and defined. The characteristics difficult to define and observe can be derived from that unconscious implicit knowledge. Therefore the implicit ones can be obtain only because of long-term obtaining of practical experiences as part of a continuous process of knowledge in an open innovation system.

Integration of external sources in symbioses with internal is necessary to adjust to constantly deepening segmentation, which reaches personal relationships expressed by one-to-one marketing. Ways of dealing are then the subject of product management. Subsequently it indicates that inside the space for integration we distinguish different levels of "labour division" between interested subjects due to the activities in the process of the value - innovation.

Subjects of internal and external environment become equal partners within companies' innovation process after opening the space for problem solving. They participate in that process as „co-innovators". The goal of that kind of cooperation in integration of external sources in symbiosis with internal sources into innovation process is the achievement of partnership in the creation of performance in community consisting of customers, users, producers, suppliers, traders and other sources of innovative knowledge.

4 Conclusion

According to the theoretical knowledge about obtaining invention sources for innovation creation, we can conclude that the company obtains suggestions and ideas (inventions) from different sources. The sources are from internal and external environment, but nowadays they are interconnected and cooperating. They are produced in an open innovation system that is based on the use of external research capacities in cooperation with its corporate internal capacities. The goal of the cooperation and integration of external and internal sources into innovation process is the achievement of partnership in the creation of performance in community consisting of customers, users, producers, suppliers, traders and other sources of innovative knowledge.

Such an open approach to the innovation process and inventions generating for creating of innovation facilitates penetration of the information flow, inventions, innovation opportunities, but also innovation within organizations and countries. Invention sources from open innovation system usually opens additional options for business start-ups, spin-off respectively spin-out companies. The process of spin-out is the result of different innovations diffusion from parent entity to the newly formed entity, resulting in the formation of start-up company.

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